University of Southern Queensland

Faculty of Engineering and Surveying

Wildlife Vehicle Collision GIS Mapping & Modelling

A dissertation submitted by

George Finlay Johnston

In fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

towards the degree of

Bachelor of Surveying (BSUR)

Submitted: October 2007

ABSTRACT

Wildlife Vehicle Collision (WVC) is a serious problem throughout Australia. The incidence of WVC and the measures to mitigate WVC are economically costly to society. The ability to identify, predict and design for the reduction of WVCs is beneficial to society in economic, ecological and moral terms.

This project had two main aims; 1) To create an efficient system for the mapping of Wildlife Vehicle Collisions (WVC) and essential surrounding landscape attributes, and; 2) to create a GIS model based on these landscape attributes that allow for prediction of WVCs.

Field surveys were undertaken to determine the spatial location of WVCs along a 25km section of the New England Highway. 43 WVCs were mapped by vehicle-based survey using handheld GPS. An efficient mapping system was developed that has the potential to be adopted by a wide range of users. Landscape variables potentially important to the occurrence of WVCs were identified using a Geographic Information System. Comparisons were made between individual WVC sites and the average for the entire length of the survey route. The differences between these were used to determine appropriate weights for the subsequent weighted raster overlay analysis.

Landscape variables that associate with WVC were identified through a combination of field mapping and GIS analysis. The identified correlation of WVCs and landscape variables enabled predictive models to be developed. Combinations of landscape variables with assigned weights were used to identify risk areas for WVC occurrence.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

George Finlay Johnston

Student Number: Q9422715X

Signature

24-10-2007

Date

Acknowledgements

I would like to acknowledge the support and assistance provided by the following people.

Dr Armando Apan from the University of Southern Queensland for his consistent support and assistance provided whenever requested.

Mr Gerard J Brennan from the Crows Nest Shire Council for providing the shire's "Land Management Data Resource CD" and the "Land Management Interactive CD" that contained a large proportion of the base GIS data required to undertake this project.

Mr Jason Anderson from the Queensland Government Department of Main Roads for providing additional GIS datasets and aerial photography.

Ms Megan Brady from the University of Queensland for her assistance and support in fieldwork including species identification and provision of ecological advice.

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Chapter 1 Introduction

1.1 Problem overview

Wildlife Vehicle Collision (WVC) (see Figure 1) is a serious problem throughout Australia (Ramp & Croft 2002). The incidence of WVC and the measures to mitigate WVC are economically costly to society (Magnus 2006). The ability to identify, predict and design for the reduction of WVCs is beneficial to society in economic, ecological and also moral terms.

Figure 1. Identifiable result of a Wildlife Vehicle Collision

Despite this importance, limited WVC research has occurred within Australia, and the majority of research relates to macropods or the assessment of existing mitigation strategies for macropod WVCs, with little regard for other species or mitigation techniques. The ability to model incidents of WVC could have a profound effect on road design principles in the area of route determination and the location of mitigation strategies. This paper therefore investigates mapping and GIS modelling techniques for the determination of WVC hotspots.

1.2 Aims & Objectives

This project has two main aims: a) to create an efficient system for the mapping of Wildlife Vehicle Collisions (WVC) and essential surrounding landscape attributes and b) to create a simple GIS model based on these landscape attributes that allows for the prediction of WVC hotspots.

Objectives

1. To develop mapping protocols that meet both data acquisition and positional accuracy requirements
2. To develop appropriate field methodologies for the capture of WVCs
3. To develop GIS modelling techniques that correlate relationships of WVCs to the surrounding landscape

Project Specification

1. Research previous studies within Australia and overseas, assessing their techniques and outcomes.
2. Identify the study area for this project.
3. Obtain applicable datasets from relevant data custodians. Build relationships with relevant authorities that may benefit from this research.
4. Assess the spatial accuracy required for GPS data. Acquire appropriate GPS hardware and develop mapping protocols that will meet both data acquisition and positional accuracy benchmarks.
5. Develop methodologies and undertake the field survey to capture WVCs.
6. Reduce, audit, collate and input all data acquired from field survey.
7. Use GIS software to view, manipulate and assess datasets. Investigate possible relationships between WVC data and surrounding natural and human features in landscapes.
8. Devise modelling techniques that will correlate relationships of WVCs to surrounding landscapes. Validate or assess the accuracy of the model.

Chapter 2 Literature Review

2.1 Impacts of roads and wildlife vehicle collisions

Wildlife Vehicle Collisions (WVC) occur throughout the world. The impacts of WVC effect society in economic, welfare and conservation terms (Bender 2001). The occurrence of WVC within Australia is increasing due to increased vehicle numbers, road densities, road pavement widths and vehicle speeds (Bender 2001).

2.2 Economic impacts

Vehicle damage due to collisions with large mammals costs Australia tens of millions of dollars each year (Ramp & Croft 2002). The entire economic cost to society is far greater due to vast sums of money being spent on wildlife roadkill mitigation strategies, wildlife fencing and public education (Magnus 2006). The New South Wales Road Transport Authority (RTA) spends $350 000 annually on WVC mitigation strategies (New South Wales Wildlife Council Inc. 2006). Records of the occurrence of WVC within Australian are scarce however, with only major collisions that result in severe vehicle damage or personal injury being reported. For example for the period of 1990 to 1994, 3296 WVCs were reported in Australia (Committee 1997). This figure only represents accidents that were reported to police.

Collisions with large animals have greater potential costs. It is estimated that an average cost of $3000 is associated with every individual collision between large Kangaroos and vehicles (Bender 2001). A large industry has developed within Australia to arm vehicles against damage resulting from Kangaroo vehicle collisions. Infrastructure such as bull bars, side rails and ultrasonic devices are readily sold within Australia. However, the Shu Roo ultrasonic deterrent device proved to make no difference to the number of kangaroos hit when fitted to a vehicle (Bender 2001).

2.3 Ecological impacts

The effect of roads on fauna and flora is considerable (Forman & Alexander 1998; Queensland Department of Main Roads 2002). Direct loss of habitat, habitat fragmentation, genetic isolation, dispersal barriers, direct fatalities and behavioural changes are some of the impacts modern roads have been shown to have on both fauna and flora. Further impacts still include increases in soil density, temperature, soil water content, dust, surface water, storm water runoff, sedimentation, heavy mentals, salts, organic molecules, ozone and nutrients (Trombulak & Frissell 2000).

Direct loss of habitat generally occurs in the construction, maintenance and expansion (widening) of roads. The impact of this habitat loss extends past the visible pavement with adjoining road reserve areas affected by associated infrastructure and landscape scale effects impacting on animal movement needs through associated habitat fragmentation.

Habitat fragmentation is considered to be a loss in the contiguity of habitat through disturbance (Forman & Alexander 1998). The construction of roads through habitat has the effect of bisecting or dividing the existing natural systems and landscapes. Fragmentation that results in smaller habitat patch size has been shown to reduce species diversity and richness (De Santo & Smith 1993). The ecological importance of fragmentation has been realised with research into its effects now a major focus in conservation biology (Spellerberg 1998).

Fatalities resulting from WVCs can have a negative effect on wildlife population dynamics and persistence with the possibility of local extinctions, which in turn can also lead to regional extinction (Forman 1995; Goosem 1997). Fox (1982) identified localised extinction of brush-tailed rock wallabies (*Petrogale penicillata*) directly resulting from the construction of a road adjacent to their home range. However, mitigation of direct fatalities by fencing identified a ‘catch 22’, in that fenced WVC hotspots can result in similar population impacts to the WVCs themselves due to the creation of an increased barrier effect and therefore reduced species persistence (Jaeger & Fahrig 2004).

The ‘barrier effect’ refers to the direct result of a restriction in movement of fauna due to roads (Forman & Alexander 1998). The concept relates to the need and the physical and conceptual ability for animals to move, migrate and disperse (Queensland Department of Main Roads 2002). The construction of a road places barriers within a species home range, due to either the physical inability to cross the open expanse of road, or the direct mortality as a result of a crossing attempt.

Not all species however are negatively affected by the construction of roads. Exotic species have been shown to disperse more readily along road corridors due to the removal and stressing of native species and creation of more accessible movement corridors (Trombulak & Frissell 2000). Frogs, snakes and predator species such as foxes, dingos and possibly the Tasmanian Devil have all been identified as using roads as movement conduits (Forman 1995).

2.4 Human social impacts

The effects of WVC on humans are varied between individuals. Most individuals that survive an incident with little or no damage to themselves or their vehicle are left feeling distressed for killing or maiming a wild animal. Large mammals provide the greatest risk to humans with an estimated 507 000 people injured or killed annually as a direct result of WVC within Europe alone (excluding Russia) (Bruinderink & Hazelbbroek 1996). Romin and Bissonette (1996) also reported 538 000 deer vehicle collisions in the United States in 1991. These collisions resulted in 100 human fatalities and 7000 motorists being injured. The estimated annual cost associated with human fatality and injury is $200 million (US$) (Ramp & Croft 2002). In comparison to Europe and the US, the lack of large native ungulates in Australia may lessen the direct impact of WVC on humans. However WVC of smaller native animals within Australia should be considered just as important.

2.5 Why do Wildlife Vehicle Collisions occur?

While the reasons for WVCs are complex and interrelated, three major factors that potentially create WVC scenarios include road design, road user behaviour and animal behaviour (Bender 2001).

2.6 Road design & management

Road design features have been shown to be important for WVCs through impacting driver visibility of wildlife. Roads designed with sharp horizontal and vertical curves increase the frequency of WVC by reducing sight distances for both humans and animals (Magnus 2006). Sight distance for animals, as well as humans, is important to reduce fright and the potential for wildlife to flee across roads. Verge design attributes such as steep batters, guardrails, bridges, drains and fences increase the incidence of WVC through restricting wildlife escape routes (Magnus 2006). Klocker et al. (2006) identified that fences close to roads increase the likelihood of WVCs with Kangaroos in outback Australia.

Verge management is also important for reducing WVCs. Road verges that contain vegetation have the potential to attract kangaroos (Klocker et al. 2006). Huijser et al (2006) found that having wider shoulders and mowing wider verges reduced WVC on the Montana Highway No.83. Magnus (2006) also outlines that the removal of attributes appealing to wildlife along road verges, such as water and palatable plants, will reduce the incidence of WVC. However this also increases the expanse of open area, creating larger barriers to animal dispersal.

2.7 Wildlife behaviour & movement needs

Roads generally bisect habitat of wildlife (Forman & Alexander 1998) creating a barrier to their movement (Laurance et al. 2004; Marsh et al. 2005; Rondinini & Doncaster 2002). Animals however need to move through the landscape for a variety of reasons including daily foraging (for food), finding mates and juvenile dispersal (Forman 1995; Van Dyck & Baguette 2005). Movement of animals through landscapes is necessary for maintaining genetic variation within populations. Without movement of individuals between populations and across the landscape, demographic and genetic effects of isolation can be damning for a species (Kozakiewicz 1993).

Not only do animals often need to cross roads that bisect their habitat, road reserve verges can also serve as movement conduits and provide critical habitat. Lynch et al. (1995) found road reserve verges provided movement conduits between habitat patches, feeding territories and breeding sites for some bird species. While Arnold & Weeldenburg (1990) found the number of bird species using road verges increased significantly with verge width, with vegetation widths of >10m increasing suitability. This was also found to vary slightly depending on the season. The importance of road verges for wildlife could also increase if the road verge vegetation represents a large proportion of the suitable habitat left in a region, or also during periods of drought when more habitat may be needed.

Mammal species have been consistently reported using road verges. Macropods may move onto edges of roads to specifically utilise water that collects there (Coulson 1989). Osawa (1989) also found road verges provided important feeding habitat for swamp wallabies. Taylor & Goldingay (2004) found thick grass next to roads provided suitable foraging habitat for bandicoots, and trees immediately adjacent to road corridors provided habitat for possums. The particular species that are able to use roadside habitat may be more likely to contribute to WVC numbers.

The Darling Downs region consists of predominantly agricultural land uses with a high percentage of road reserves containing native or remnant vegetation (pers. obs.). It is therefore feasible that vegetated road verges within the selected study region would provide many services for existing native and exotic flora and fauna. Within the selected road corridor the existence of mature trees may create a point of conflict between vehicles and fauna (for example possums).

2.8 Road users

Education of road users could reduce the potential for WVCs through increasing awareness of the potential impact as well as highlighting WVC hotspots through signage. Signs warning of WVC hotspots could give drivers an ability to slow down and change their driving behaviour in high-risk areas.

In order to be able to educate the public however, managers first need to be able to identify the higher WVC risk areas. A simple GIS tool could allow this, and perhaps more importantly may help to locate roads away from high-risk WVC areas or also to put in place WVC mitigation techniques on existing roads.

2.9 Direct WVC Research within Australia

The majority of previous WVC research within Australia directly examines the occurrence and mitigation of incidents with Macropod species (eg.Bender 2001; Coulson 1989; Coulson 1982; Klocker et al. 2006; Ramp & Croft 2002) or threatened or endangered species such as Koalas (eg.Canfield 1991; Dique et al. 2003). Mature male kangaroos are the largest native mammal within Australia. Higher funding for research on macropod WVCs may occur given the greater economic and human impacts associated with WVCs with larger animals, however smaller animals (including Koalas) also make up a significant proportion of WVC incidents (pers. obs.).

Ramp and Croft (2002) assessed WVC along the Silver City Highway in NSW with specific objectives to assess macropod behaviour, density and possible mitigation strategies. The findings reinforced the need for standardised recording of WVC information, as the collation of statewide data would assist in increasing understanding of the impacts of road-kill on fauna populations. The current study will therefore adopt many of the techniques for field observation that were developed by Ramp and Croft (2002). This will allow for direct comparisons with previous and future WVC research.

Klocker et al. (2006) examined frequency and causes of kangaroo-vehicle collisions on an Australian outback highway. He found a positive correlation between nighttime traffic volume and WVC. McCafferty (1973) found that WVC of Wisconsin deer was directly proportional to traffic volume and Osawa (1989) noted a similar finding with Swamp Wallaby in North Stradbroke Island.

Earlier research into macropods and road mortality through WVC included Coulson's (1989) investigation into the effect of drought on road-kill incidence in which an increase in occurrence was identified. Current drought conditions may therefore affect the proposed field survey macropod road-kill numbers. It is assumed that other species will be affected by this drought, although it is unknown whether there will be an increase or decrease in their numbers. Coulson (1982) undertook a specific survey of Macropod road-kill on a section of central Victorian highway. He noted that kangaroo warning signs were not effective in the reduction of kangaroo fatalities. The limited success of signage suggests more research is required into mitigation strategies and predictive modelling for the implementation of such strategies.

Other potential influences on the incidence of WVCs have included moon phase. Coulson (1982) found increases in kangaroo fatalities during full moon lunar events. However Osawa (1989) found no such impacts from lunar phases on WVCs with Swamp Wallabies (*Wallabia bicolour).* Variations in animal behaviour and movement due to changing lunar phases will be appreciated within the current study.

The characteristic of the surrounding landscape is also important to WVCs. Biophysical attributes such as type and percentage of land use and the type and percentage of vegetation or other habitat needs such as water within an area of a road corridor are important to the location of wildlife along the corridor and suitable field site coverage for the investigation of these landscape attributes is fundamental. Different fauna species possess varying home ranges and habitat needs that should govern the selection of a field site range. Osawa (1989) utilised a 300m radius site to identify landscape characteristics in a study investigating the effect of WVC's on Swamp Wallaby persistence. Huijser et al. (2006) adopted a 500m to 1000m offset from either side of the study road to investigate landscape characteristics for vehicle and deer collisions. Within the current study, pilot data has identified small and medium sized mammals as the major WVC victims within the chosen study area. Perception and home range movement of small and medium-sized mammal species is much lower than macropods and large ungulates. Perception range of species likely to be encountered in the major phase of field sampling varies between 80 and 500m (Dickman & Doncaster 1989; Fitzgibbon 2005; Pavey et al. 2003). The current study will therefore use a maximum of a 200m offset from each side of the study road.

Non-Macropod specific WVC research within the last ten years has been limited with only four published studies being found to date (Goldingay & Taylor 2006; Ramp et al. 2005; Taylor & Goldingay 2003, 2004). Goldingay & Taylor (2006) studied the number of frogs killed on roads in north-east New South Wales and highlighted the poor documentation of WVC for this group of fauna. Taylor and Goldingay (2003; 2004) and Ramp et al. (2005) investigated non-species specific road wildlife fatalities from vehicles.

Taylor and Goldingay (2003; 2004) examined the incidence of WVC, techniques to survey WVC and the effectiveness of barrier fencing and underpasses (culverts). The vehicle based survey techniques used proved to be limited in the ability to identify and record smaller species, for example frogs. Other smaller species including mammals, for example rodents, may therefore also be difficult to observe using these methods. The inability to identify smaller species consistently whilst driving has implications that will be considered for this current WVC study. Further, although Taylor and Goldingay (2003; 2004) undertook comprehensive investigations into the abundance of WVC, they did not accurately locate each WVC position using GPS, or utilise spatial analysis techniques within a GIS. Ramp and Croft (2002) identified that there was poor quantitative information relating to spatial and temporal patterns of WVCs throughout Australia in general.

Following this conclusion, Ramp et al. (2005) undertook a comprehensive WVC study on the Snowy Mountain Highway in NSW. This study is the most comprehensive yet to occur within Australia. The study utilised GPS, GIS and modelling techniques to identify WVC hotspots. The methods employed in this research are complicated, with numerous ecological processes being assessed and modelled. The outcome of this research may therefore not be accessible to the entire public including local road managers, but may be more suited to the scientific community. It is important to produce a simple tool and protocol that can be utilised by all levels of management.

Despite non-macropod specific WVC research in Australia being limited, substantial research into the impacts of roads and other linear infrastructure on population dynamics of small and medium-sized mammals does exist within the conservation biology literature. Reviewing these ecological papers in depth is however outside the scope of this study, although major findings will be considered for their correlations with the major results of the current study.

2.10 Current WVC Mitigation Strategies

Once WVC hotspots have been identified, possible mitigation strategies can be adopted. Current WVC mitigation strategies include obstruction and redirection of animals, alerting drivers of the presence of animals and alerting animals to the presence of vehicles (Bender 2001). Physical mitigation techniques that are currently used within road reserves include tunnels, fences, funnels, bridges, reflectors, overpasses, underpasses, culverts and signage (Queensland Department of Main Roads 2002).

A visual cue through signage is the most common technique used for driver awareness of wildlife (Bender 2001). The effectiveness of signs for reducing vehicle speeds and increasing driver awareness is questionable. Coulson (1982) found no variation in WVC numbers after the local authority placed kangaroo warning signs on an 8 kilometre section of road in Victoria. Pojar et al (1975) identified that deer carcases left on a road verge slowed motorists more than an animated deer crossing sign.

Mitigation strategies to warn animals of the approach of vehicles generally occur through sonic or visual cues (Bender 2001). Sonic devices such as the Shu Roo have been shown to be ineffective in deterring kangaroos from interacting with approaching vehicles (Bender 2001). Visual devices such as Strieter-Lite, Wegu and Swareflex reflectors refract light from approaching vehicles perpendicular to the road.

The refracted light produced by the reflectors creates an optical warning fence. The effectiveness of visual warning devices for macropods is questionable (Bender 2001; Ramp & Croft 2002).

Obstruction and redirection of animal movements is most commonly achieved through fencing (Bender 2001). Fences can direct animals to safe road crossing points such as overpasses and underpasses or areas that are significantly identified as wildlife crossing points. Funnel fencing which directs wildlife to an appropriate road crossing structure can have significant benefits for some species (Queensland Department of Main Roads 2002). A significant project that has implemented funnel fencing and designated fauna road bridges is the Compton Road Project in Brisbane. The Compton Road upgrade has adopted numerous fauna sensitive design principles. The effectiveness of these designs is still being assessed (Sauter 2006). It is apparent that the most effective strategy to mitigate WVC with current technology is to restrict animal and vehicle interaction through physical barriers. Methods that physically block animals moving onto roads, yet still allow for movement and dispersal needs would appear the best solution for both road users and wildlife.

The financial cost to implement conceptual barriers through reflectors and physical barriers through fences and physical access points through overpasses or underpasses to protect wildlife and humans is considerable. To effectively implement cost effective mitigation strategies, the location of WVCs have to be mapped and analysed both spatially and statistically. The analysis of WVCs spatially and statistically using GIS will ensure efficient expenditure by federal, state and local authorities on mitigation strategies.

2.11 GIS as a tool for mapping and modelling WVC

GIS has been utilised for numerous spatial analysis studies. Ramp et al. (2005) utilized GIS to analyse the spatial clustering of WVCs and their relationship to landscape variables on the Snowy Mountain Highway in NSW. Huijser et al. (2006) used a GIS to model WVCs on the Montana Highway, US. It appears that the spatial analysis capabilities of GIS provides an effective tool to assist in the modelling of WVC hotspots and possibly assisting in locating future roads. The key to reducing the incidence of WVC appears to be in creating a simple and effective modelling tool that can be utilised by Federal, State and Local Authorities.

2.12 Summary and gaps in knowledge in relation to current study

A number of gaps are evident within the current literature. Firstly, the majority of previous research into WVC within Australia has focused only on macropod species. Secondly, there does not exist an accurate standardised method for the recording of WVC, in order to effectively locate positions for WVC mitigation measures. The most effective method for reducing the incidence of WVC has been shown to be the physical obstruction of wildlife entering road corridors and the redirection of animals over or under roads. To accurately locate WVC hotspots, a larger WVC dataset using standardised methods is needed that guarantees picking up all fauna fatalities, rather than just larger species. The complexity of the surrounding landscape and the number of attributes influencing the occurrence of WVC needs to be simplified, while ensuring the attributes remain ecologically sound. Finally, the capability of modern GPS and GIS techniques have not been adequately utilised in developing a system for managers.

The current project therefore aims to develop a simple, accurate, standardised system for the mapping and recording of WVC. It will investigate relationships with the surrounding biophysical landscape and assess the most efficient attributes for correlations with WVC and inclusion in the system. Modelling techniques will be devised and the validity and usefulness of models to locate WVC hotspots will be assessed.

Chapter 3 Methods

3.1 Study Area

The New England Highway (NEH) between Toowoomba and Hampton within the Crows Nest Shire has been selected as the study region due to the continual occurrence of WVC along this road over the last decade (pers.obs.). The region is located in southeast Queensland upon the Great Dividing Range. The predominant land use in the region is agriculture, mainly grazing. Broad scale clearing of remnant vegetation occurred prior to the 1930's and now rapid urban expansion is occurring (Brady unpub. data).

The NEH follows a route north from Toowoomba (see Figure 2) with a four-lane carriageway to the satellite suburb of Highfields. The land use between Toowoomba and Highfields consists of acreage residential, agriculture and small commercial ventures. Highfields is one of Queenslands fastest growing residential regions, with most residents commuting to Toowoomba for employment, education and social needs.

North of Highfields the NEH continues as a two-lane carriageway through patches of cultivation, grazing, low density residential, remnant vegetation and small commercial ventures. Vegetation on the NEH verges becomes more prominent in this region. After Highfields the NEH continues through Cabarlah. Cabarlah consists of a convenience shop, hotel, tourist shop & cafe, nurseries, showgrounds and low-density residential areas. From Cabarlah the NEH traverses through Geham to Hampton (Figure 1). The route consists of mainly rural landscapes in this section. Geham landfill dump is a notable landmark.

Existing vegetation along the highway verges between the Geham dump and the settlement of Hampton is considered significant (Sparshott pers. comm.). The Queensland Department of Main Roads has recently scanned vegetation located on the road verges using vehicle mounted 3D scanners in an attempt to minimise vegetation removal for future road expansion. The department has identified that this vegetation holds tourism and environmental conservation value (Anderson pers. Comm.).

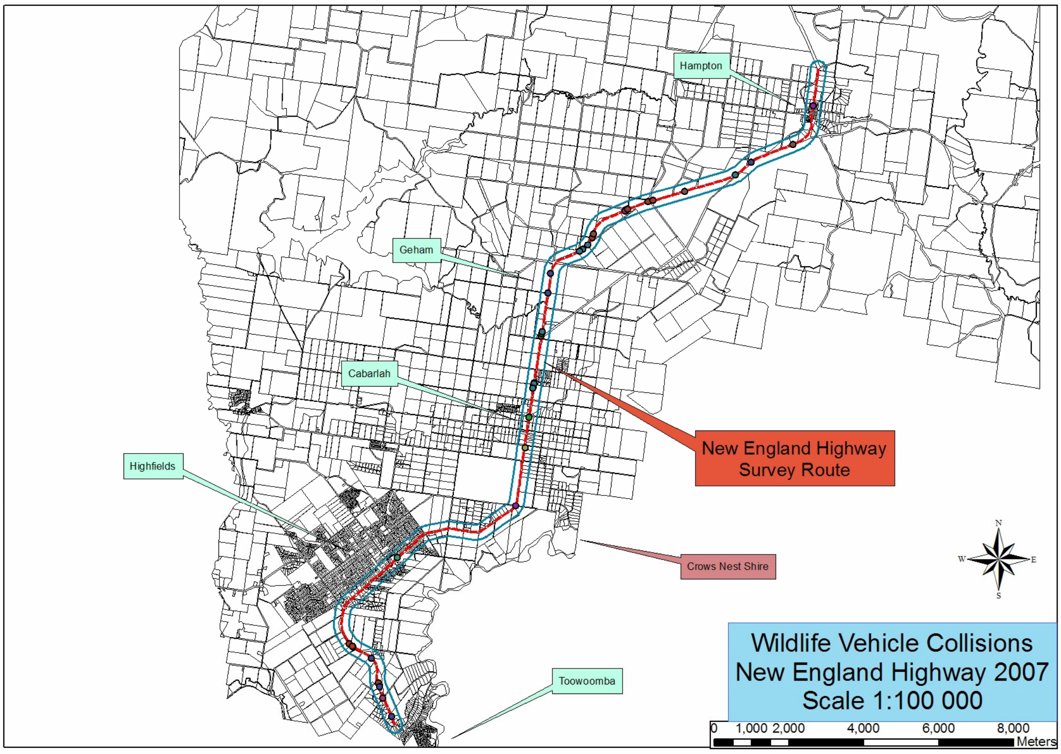

Figure 2. Study area showing New England Highway (NEH) survey route

(Refer to appendix D for enlarge image)

Just south of Hampton there is a dramatic change in land use with the existence of tree plantations. These plantations are for the production of timber suitable for milling and consist of varying species of pine, with a regenerating native & weedy understorey (pers. obs.). Commercial and community infrastructure include a local store, a well-frequented tourist information centre, antique furniture shop and coffee shop. Low-density residential and small acreage farms exist around the perimeter of the settlement and agriculture and forestry are the predominant land uses.

The peak traffic volume for the study section of the NEH occurs during mornings and afternoons when people commute to and from Toowoomba. This road also caters for tourists and vehicle enthusiasts during weekend periods (pers. obs.).

3.2 Software, Hardware & Data Acquisition

3.2.1 Software

The basis of this project is to use a Geographical Information System (GIS) as a tool in the prediction of wildlife vehicle collisions. Acquiring suitable software to undertake this research was a first priority. Earth Sciences Research Institute (ESRI) were approached and provided ArcGIS 9 for twelve-months under a free student licence agreement. The software provided contains all required extensions for this project including Spatial Analyst, Geostatistical Analyst, Network Analyst and 3D Analyst.

3.2.2 Hardware

An existing personal computer (PC) has been utilised for all computing based activities. The Optima PC consists of a Pentium 4, 2·66GHz CPU with 1 gigabyte of ram shared for graphics. The monitor is a 19inch LCD flat screen. Input devices include multimedia keyboard, optical mouse and USB ports. Output mediums include CD, floppy disk and varying size memory sticks.

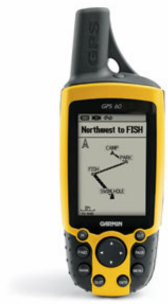

Figure 3. Garmin GPS60 handheld unit used for field survey

GPS field measurements will be achieved using a Garmin GPS60 handheld navigation system (See Figure 3). The system consists of a water proof casing, 160*240 pixel 4-level grey LCD with back lighting, built-in quad helix antenna (with remote antenna capabilities), 12 parallel channel receiver and its accuracy is rated at better than +/-15m 95% of the time with selected availability turn off. The accuracy of this handheld GPS appears to substantially exceed that stated by the manufacture. The GPS onboard software allows the user to average waypoint positions over extended periods of time. The increased observation periods appear to increase waypoint accuracy and integrity.

3.2.3 Data Acquisition

The analysis of geophysical relationships in this project was based on existing GIS datasets. Acquisition of data is paramount and has determined the overall project direction in site selection and analysis.

The Environmental Protection Agency, Department of Natural Resources & Water and State Herbarium were initially contacted for advice on availability of appropriate GIS datasets. There was limited success in gaining information about the existence of data, the process of acquiring the data, the costs of data and the data agreements that would have to be entered. The State Herbarium proved to be the most approachable organization.

The Queensland Department of Main Roads (MRD) was also approached to acquire relevant data. Peter Sparshott (Environmental Officer, MRD Southern District) and Jason Anderson (GIS Officer, MRD Southern District) were contacted. The MRD provided useful datasets, which included:

- Road Names
- District Drainage
- Threatened Fauna
- Local Government Zones
- Aerial Photography
- Road Classification
- Town Names
- Ecologically Classified Road Reserves

All data provided was in a MapInfo raw format and an ECW format for imagery. These datasets required transformation and use of an ECW JPEG compressor for imagery before being accessible within ArcGIS.

Crows Nest Shire Council (CNS) also provided data in the form of an interactive mapping CD on land management guidelines. This CD contained numerous data layers that were applicable to this research. The interactive CD's provided by CNS contained ESRI Shape files that were suitable for direct import to ArcMap. CNS has shown an interest in any results from this study that could assist in future planning.

Dr Armando Apan from the University of Southern Queensland (USQ) provided the project with the "South East Queensland 25 metre Digital Elevation Model - SEQ_DEM_100K. This dataset was sourced from the Queensland Department of Natural Resources & Water. This data enabled the assessment of topographic variables such as elevation, aspect and slope. All GIS datasets were provided free of charge specifically for educational purposes.

3.3 Field Survey

3.3.1 Pilot Study

Given the complexity of researching WVCs, a pilot study was undertaken to assist in identifying field requirements for the project. The pilot study field survey occurred over the entire month of February 2007. The pilot study assessed and developed field procedures that were utilised for the final field survey. The pilot study methods were identical to those adopted in the final survey. These methods are discussed within the final survey methods section.

3.3.1.1 GPS Spatial Accuracy

Assessment of the spatial accuracy of the Garmin GPS60 in adverse GPS conditions was undertaken. The test location consisted of approximately 40% tree cover, a power line and an obstruction to the south by a building. Approximately 30% of the sky was unobstructed. The same position was recorded on 4 different days with varying initialisation and logging times.

3.3.1.2 GPS Datum Assessment

To test the GPS coordinate datum configuration the GPS was assessed against a known first order permanent survey mark (PSM). This quality assurance check would determine if the WVCs recorded by the GPS are on the same coordinate datum as the GIS datasets (i.e. UTM zone 56 WGS84).

3.3.2 Final Survey Method

A vehicle based survey technique was utilised to locate WVCs. The vehicle was driven at a maximum speed of sixty kilometres per hour for the entire survey route. The limiting of the maximum speed ensured smaller animal species should be recorded.

The location of the WVCs was undertaken by hand. The vehicle was park clear of the carriageway and the location and documentation of the WVC occurred on foot.

Five survey trips where undertaken in August 2007. No more than 4 days lapsed between each survey as WVC incidences can deteriorate preventing observation and or correct identification.

Data from both the pilot study and final survey were combined for analysis. Field methodologies utilised during the pilot study were considered adequate to enable inclusion within the overall WVC dataset. The entire WVC survey was therefore undertaken over a six-week period with 12 individual surveys occurring. Further surveys would have been beneficial, however time constraints prevented this.

3.4 GIS Mapping

WVC positions were mapped using a Garmin GPS60 waypoint that has been logged for approximately 30 seconds and displays a calculated positional accuracy better than (+/-) 5m. The waypoint was coded using a unique point identifier and abbreviated species name. To increase the value of field survey data, three digital photographs were taken consistently at each WVC. These digital photographs included;

1) Animal remains (WVC)
2) Landscape left, perpendicular to road centreline (generally west)
3) Landscape right, perpendicular to road centreline (generally east)

The digital photographs are an integral part of the field survey data as they provide additional information of site characteristics and confirmation of species identification. It is believed that the digital photographs (Appendix R) increase the dataset useability and value through identifying specific ground monuments that could be revisited for additional field surveys such as transects to precisely identify habitat and landscape variables. Figure 4 illustrates the protocol followed during the field surveys.

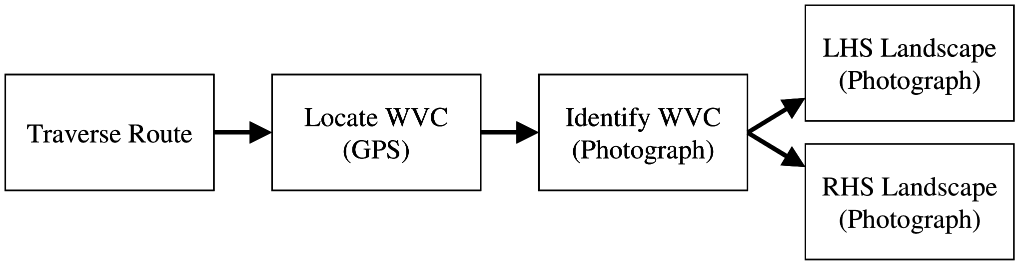

Figure 4. Field survey protocol used to locate & map WVC incidences

3.5 GIS Modelling

Geographic data from two main sources was obtained and imported into ArcMap. This process required data manipulation of both existing GIS datasets and the WVC coordinate data. Effective management of the datasets at this stage was imperative for achieving the overall project aims.

Spatial coordination of the project was determined by the Garmin handheld GPS. The Garmin GPS60 only allowed for a Universal Transverse Mercator projection that utilised WGS84. This restriction required all datasets to be transformed from GDA to the new coordinate system. While this transformation is not required, as the positional accuracy of the handheld GPS would not exceed the datum variations, GIS dataset transformations were undertaken to maintain uniformity between data layers and WVC coordinate data.

3.5.1 Data Manipulation

To create the predictive model it was necessary to develop a GIS database. The GIS database develop defined all the landscape variables that would be analysed. To build the database all data had to be in appropriate format for importing into ArcMap.

3.5.1.1 WVC Coordinate Import

Figure 5 illustrates the process followed for import of the WVC coordinates into ArcMap. Raw coordinate data derived from GPS observations was downloaded to the computer via a USB cable. The software link between the PC and the Garmin

GPS was obtained through the manufacturer's software MapSource. ArcMap is capable of receiving raw GPS coordinates direct from a range of handheld GPS units, however, MapSource was utilised for its ability to export simple ASCII text files that provide greater flexibility for raw data manipulation.

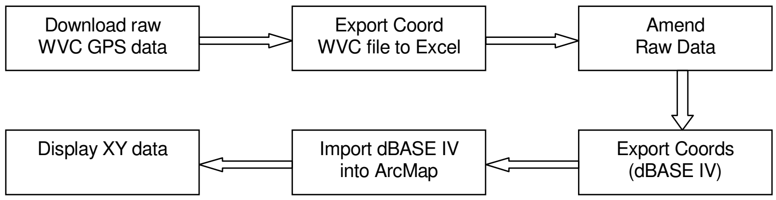

Figure 5. WVC coordinate import procedure

MapSource immediately displays all data that is contained within the GPS once the USB download process has been completed. An ASCII file was created utilising the export function within the software. This file was then amended in Microsoft Excel to remove superfluous information such as GPS Tracks and the changing of the text format to create an appropriate text structure for the import into ArcMap. Examples of typical raw and amended ASCII files can be found in appendix B and appendix F Respectively.

After amendments the raw GPS data was imported to ArcMap using the 'Add Data' function found in the file drop down menu. Selecting the appropriate file within ArcMap's table of contents and then selecting "Display XY Data" and highlighting the appropriate fields displayed the coordinate data.

The WVC symbology was set within ArcMap to display individual WVC points with an easily discernable icon. At this stage the WVC coordinate data was contained within ArcMap and ready for landscape variable analysis.

3.5.1.2 ESRI shapefile-GIS Data Import

The GIS datasets provided from CNS were in an ESRI shapefile format suitable for direct import into ArcMap. Figure 6 illustrates the procedure followed to import the files and make the datasets suitable for analysis.

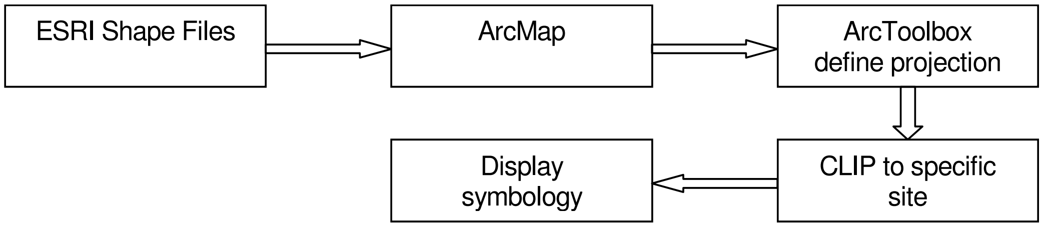

Figure 6. Procedure followed for GIS shapefile import and manipulation

Files were imported using the "Add Data" function within ArcMap and then converted to the new datum using the "Project" function found within ArcToolbox. The datasets converted in this manner included:

- Digital Cadastral Database (DCDB)
- Foliage Projective Cover (FPC)
- Land Use
- Remnant Vegetation
- Digital Elevation Model (DEM)

At the completion of the import process all layers were clipped using a site area layer that defined the bounds of the area of interest. The defining of the site area was undertaken to create a manageable area for the GIS model output, as well as to reduce computer file sizes and computation times. This process is detailed in section 3.5.2.

Each GIS data layer was configured to display appropriate colours using the "Properties & Symbology" functions within ArcMap.

3.5.1.3 MapInfo TAB file-GIS Data Import

GIS data provided by MRD was in a MapInfo TAB format only suitable for use within MapInfo. Given this data incompatibility MapInfo was sourced to convert all MRD TAB files to an Interchange Format. Once the MapInfo Interchange Format (MIF) files had been created the import process occurred in the same manner as described in section 3.5.1.2. Figure 7 illustrates this procedure.

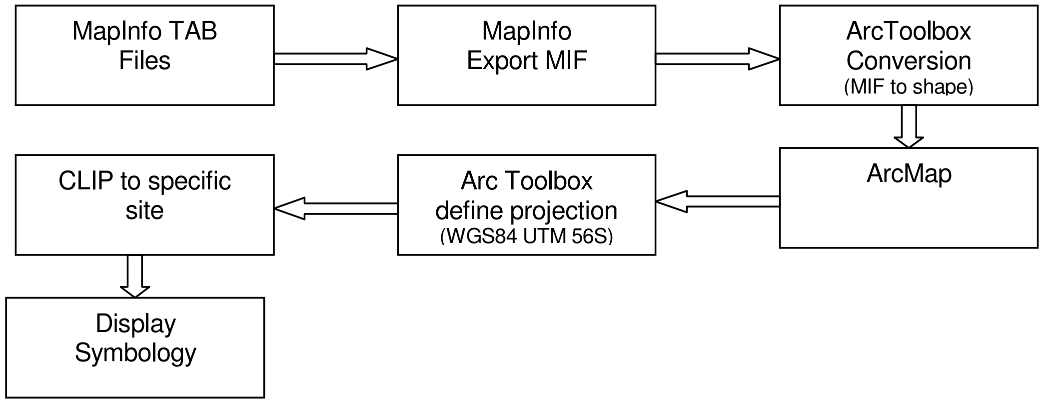

Figure 7. Procedure followed for MapInfo TAB file manipulation & import into ArcMap

The datasets converted in this manner included:

- District Zones
    - Local government zones as defined under the Integrated Planning Act.
- District Parks
    - Parks and nature reserves.
- Town Dots
    - Town names.
- Eco Roads
    - Road polylines that contained attributes defining the ecological rating of the road reserve.
- Roads
    - Road polylines that contained name attributes

Aerial photography was obtained from MRD and was displayed in ArcMap using a free ECW JPEG compressor program. The aerial photography is used only for presentation purposes.

3.5.2 Site Coverage Clip

The GIS dataset files used covered a larger area than that required for this project. Each dataset was reduced in size to maximise computer storage and increase processing speed. AutoCAD was used to create a rectangle that defined the site area. The rectangle bound the following region:

1. 6981000 N
2. 414000 E
3. 6952800 S
4. 391000 W

This rectangle was then used to clip each feature dataset. Raster datasets were clipped using the coordinates above and the raster clip function within ArcMap's ArcToolbox. Figure 8 shows the reduced area that datasets were clipped to.

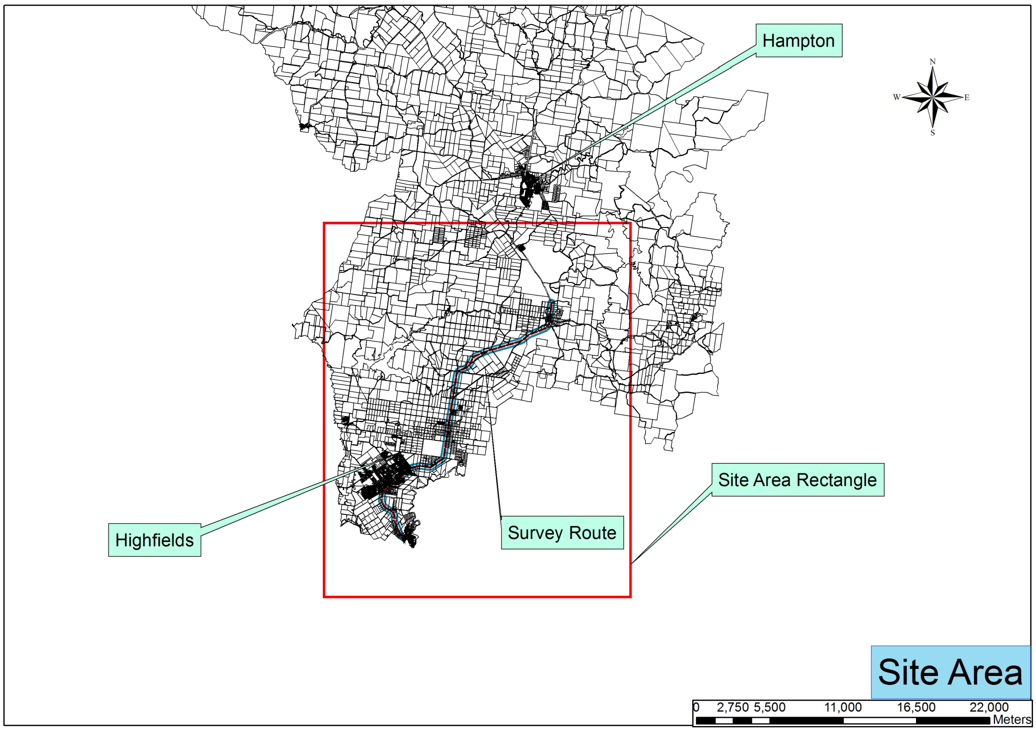

Figure 8. Area clipped from GIS datasets to become Site Area (red rectangle)

3.5.3 Buffer Analysis

Buffer analysis was used to extract landscape variables from the GIS datasets in a specific area. Buffer analysis creates a new feature class from an input feature at a given distance offset. The buffered area is then the area focused on when analysing surrounding landscape variables. Figure 9 shows a section of the study road and the two types of buffer analyses performed – survey corridor buffer analysis (hereon called 'site corridor') and WVC buffer analysis.

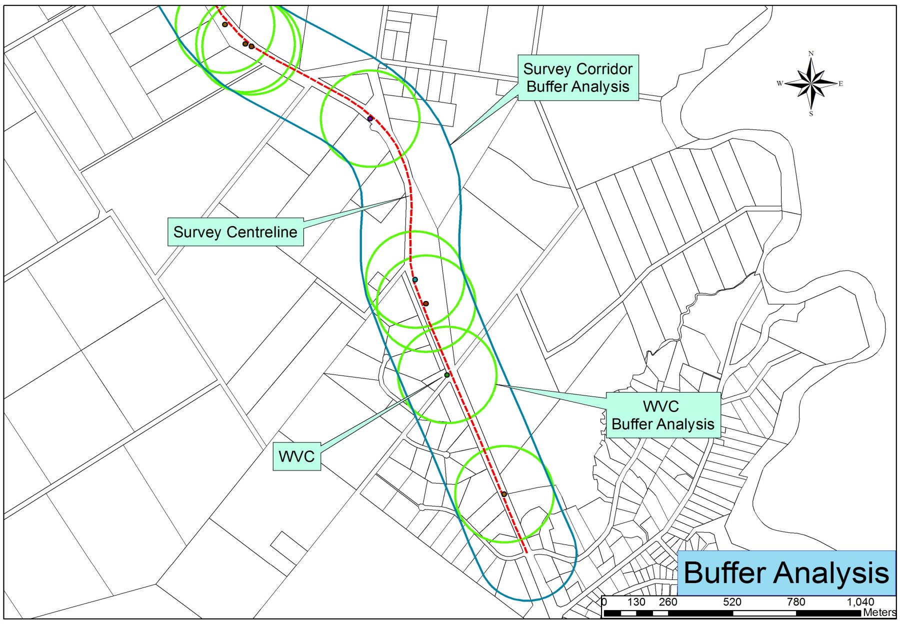

Figure 9. Buffer analyses performed: individual WVC buffers (green circles) and overall 'site corridor' (blue corridor area)

A 200-metre offset from the road centreline was used to create the site corridor. Refer to section 2.9 for reasoning of offset distance. The site corridor is then a feature that can be used to clip landscape variables and provide overall site landscape variable percentages. Figure 10 illustrates the process used for buffer analysis.

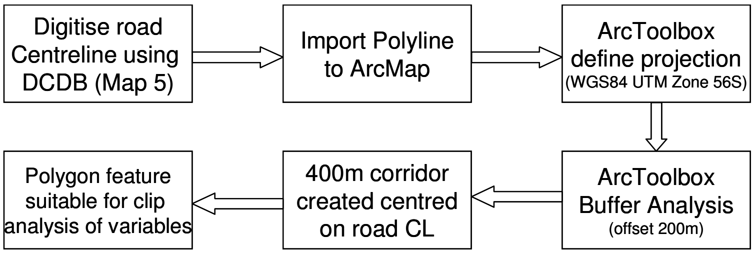

Figure 10. Procedure followed to create 200m road centreline offset buffer or 'site corridor'

Individual WVC points were then buffered using the same process as for the site corridor. The output feature from this process is a circle as the individual WVCs are defined as points and not polyline features like the road centreline.

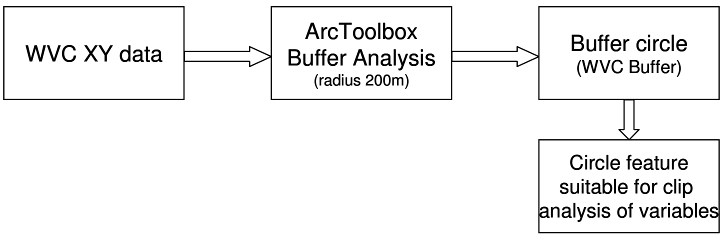

Figure 11. Procedure followed to create 200m offset buffer for each individual WVC

Creating a buffer feature for each individual WVC allowed for the clip analysis of landscape variables by defining the area of interest around the WVC. WVCs were individually buffered to provide the complete 200-metre radius coverage even when overlap was present due to WVCs being less than 200m apart.

3.5.4 Model Builder

Model Builder was utilised for several operations within this project. It is a feature within ArcMap (see Figure 12) that allows the user to string a series of events together using a schematic diagram. This process allows the user to undertake several operations simultaneously. Previous operations can also be retrieved, modified and developed, making it a useful tool.

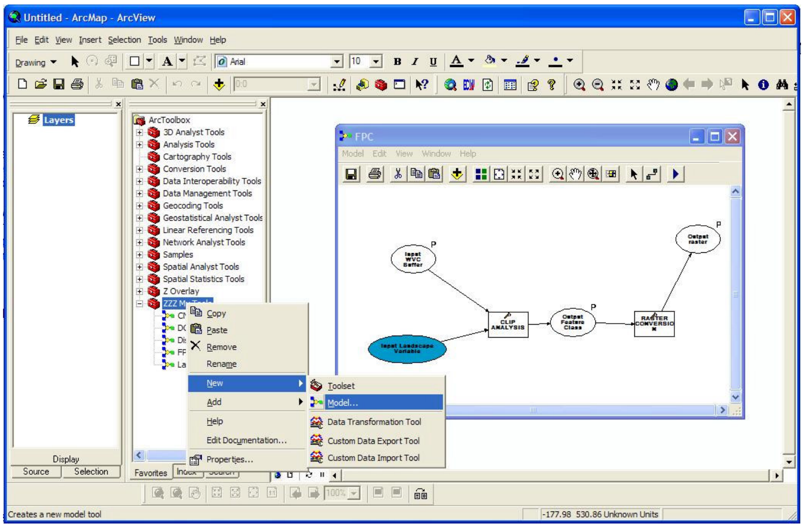

Figure 12. ArcMap Model Builder

3.5.5 Landscape Variable Extraction

From all of the acquired GIS datasets, only a selection was used. This was based on their potential importance to both the occurrence of wildlife within the road corridor (determined in consultation with a qualified ecologist) and landscape characteristics that may make road sections more or less susceptible to WVC such as slope (refer to section 2.6).

The following datasets were selected:

1. Foliage Projective Cover (FPC)
2. Land Use
3. Remnant Vegetation
4. District Zone
5. DCDB
6. Elevation
7. Aspect
8. Slope

Landscape variables form the basis of this project. The extractions of landscape variables required several processes. These processes were streamlined by using Model Builder within ArcMap.

To extract the landscape variables it is necessary to clip the landscape GIS datasets using the buffer analysis output features. The clip function requires an input feature and a clip feature. This process results in a section of the landscape variable being extracted to form a new feature class. Figure 13 shows the clip analysis process.

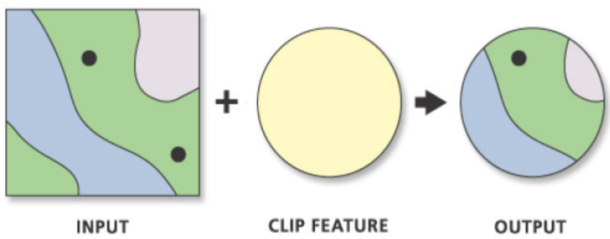

Figure 13. Clip analysis process (Source: ArcGIS help)

The input represents the landscape variable being assessed, the clip feature represents the WVC buffer feature or the site corridor feature that determines the area to be clipped and the output represents the landscape feature that will provide the landscape percentages for analysis.

To streamline this process the Model Builder schematic below (Figure 14) was developed.

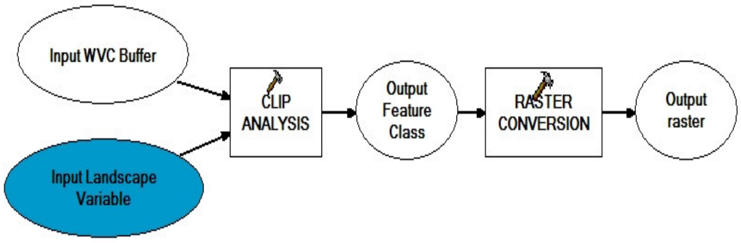

Figure 14. Model builder

This model provides the output landscape variables in a raster format suitable for table export to Microsoft Excel. The extraction process was applied to each individual WVC record so variable percentages would not be biased by overlapping buffer areas. The extraction process was also applied to the site corridor to provide overall landscape percentages.

The following GIS datasets were analysed using this process:

- Foliage Projective Cover (FPC)
- Land Use
- Remnant Vegetation
- District Zone
- DCDB

Elevation, slope and aspect were determined by extracting values to points. This method creates an additional field within the ArcMap WVC table for each DEM variable being assessed.

3.5.6 Landscape Variable Analysis

Export of attribute tables occurred at the completion of the landscape variable extraction process. Table 1 shows an output table from ArcMap for a single WVC record. Refer to appendix C for a graphical representation of the landscape attributes being extracted. Although landscape areas can be calculated from the pixel count with the knowledge of pixel size, it was not necessary as only landscape percentages are of interest.

The site corridor was defined by the buffer analysis described previously. The corridor was used to clip each landscape dataset. The clip process resulted in one output table per dataset.

Table 1. Example output table from ArcMap for a single WVC record.

ObjectID	Value	Pixel Count	Description
0	1	5372	native vegetation
1	2	2915	regrowth
2	3	23253	pasture
3	4	17540	crop - broadacre

From the tables, percentages were calculated using the following formula:

$$\text{Percentage} = (\text{Description Pixel Count} / \text{Total Pixel Count}) * 100$$

The percentages determined represented the occurrence of each landscape description within the GIS dataset being assessed.

43 separate output tables for each GIS dataset being assessed were created for individual WVCs. The tables were exported to Microsoft Excel and merged. The sort ascending function within Microsoft Excel allowed efficient grouping of landscape descriptions once the individual WVC tables had been merged.

For each dataset, the site corridor and WVC percentages were then subtracted from one another to determine the variations in occurrence (Table 2). This percent difference in landscape descriptions (RHS column below) forms the basis for the GIS dataset reclassification within the predictive model.

Table 2. Example percent difference in landscape descriptions between site corridor and WVCs

Description	% Remnant Veg {Site Corridor}	% Remnant Veg {WVC}	% Difference
Clear	77.59	79.81	2.22
Fringing	0.07	0.30	0.23
Plantation	8.63	5.79	-2.84
Tall forest	12.25	14.10	1.85
Grassy woodland	0.00	0.00	0.00
Open forest	1.46	0.00	-1.46
Rainforest	0.00	0.00	0.00
Semi-evergreen vine thicket	0.00	0.00	0.00
Shrubby forest	0.00	0.00	0.00
Woodland	0.00	0.00	0.00
n/a	0.00	0.00	0.00

Elevation, slope and aspect were analysed by frequency of occurrence. This process will be discussed in greater detail in the results section.

3.5.7 Cluster Analysis

The determination of a "cluster" or "hotspot" of WVCs is valuable for determining the appropriate location for WVC mitigation strategies. Limited literature exists within Australia that defines a "hotspot". The concept of a hotspot appears to be based on moral, economic and ecological grounds. This concept requires research to quantify and define, and is considered outside the scope of this project. However an assessment of the spatial distribution of the surveyed WVCs was performed in order to identify clusters. The defining of a cluster could enable specific analysis of the landscape variables within that region.

The landscape variables identified within the cluster regions could then be given greater weighting within the predictive model. This increased weighting based on cluster analysis should theoretically provide greater model accuracy. To identify clusters the surveying and computational package LISCAD produce by Leica-geosystems was used.

The NEH centreline and the WVC ASCII coordinate list were imported into LISCAD. The NEH centreline was converted to an alignment element. Within LISCAD an alignment joins a series of line elements together to form a polyline with a defined starting and finishing chainage. Chainages are used to locate specific points along the alignment.

Once the alignment had been defined it was possible to extract the chainage and offset of each WVC for the length of the survey route. Refer to appendix E for the alignment report from LISCAD.

Frequency histograms were then produced in Microsoft Excel using the alignment report. The histogram was set up to define the number of WVC's that occurred within each 200 metre section of the survey route. The success of this procedure will be discussed in greater detail in subsequent chapters.

3.5.8 Digital Elevation Model

The Digital Elevation Model was imported into ArcMap using the "Add Data" function and then clipped using the raster data process described in section 3.5.2. The following attributes were then extracted from the DEM:

- Elevation
- Slope
- Aspect

3.5.8.1 Elevation Analysis

Elevations were interpolated within ArcMap at each WVC location using the DEM. Heights at each WVC location were extracted and imported into Microsoft Excel. Additionally elevation differences were compared between the GPS and the DEM. These variations will be discussed in a later chapter.

3.5.8.2 Slope Analysis

ArcMap's "3D Analyst Tool" within Arc Tool Box was used to perform the raster to slope conversion. This process creates a new raster layer that defines the topographic slope. Slope at each WVC location could then be extracted and imported into Microsoft Excel.

3.5.8.3 Aspect Analysis

ArcMap's "3D Analyst Tool" within Arc Tool Box was used to perform the raster to aspect conversion. Aspect at each WVC location could then be extracted an imported into Microsoft Excel.

3.5.9 Pilot Study Analysis

This assessment involved the analysis of individual land cover percentages at varying spatial scales. Individual WVC incidences were clipped at differing radii of 200m and 500m from the WVC positions. The survey route was also assessed at the same two radii from road centreline. Buffer and clip analysis was used, as described in section 3.5.2 and 3.5.3.

3.5.10 WVC Predictive Model

The predictive model was created using ArcMap's Model Builder. This model imports multiple datasets and performs two main functions:

1. Dataset reclassification
2. Weighted raster overlay

3.5.10.1 Reclassification

Reclassification is the process of assigning new values to an input raster dataset. This process was used to create a common scale within the raster dataset. The reclassification process was applied to the following datasets:

- Foliage Projective Cover (FPC)
- Land Use
- Remnant Vegetation
- District Zone
- DCDB

Reclassification values for the GIS datasets have been determined by field survey and landscape analysis as previously described. The value applied to each dataset description was in a range between 1-5 (Table 3). This range represents the perceived risk of a WVC incidence.

Table 3. Risk assessment categories

1.	No Risk
2.	Low Risk
3.	Average Risk
4.	High Risk
5.	Very High Risk

The difference of mapped WVC data and that of the site corridor governed the assignment of reclassification values to each individual GIS dataset. For example, Table 2 shows that Clear, Fringing and Tall Forest (remnant vegetation) descriptions occurred more frequently at WVC locations than in the site corridor due to the positive percent difference. Table 4 (below) shows how the greater the positive percent difference, the higher the reclassification value assigned.

Table 4. Example determined reclassification values

Dataset	Description	Reclass
Remnant Veg	Clear	5
	Fringing	2
	Plantation	1
	Tall forest	5
	Grassy woodland	1
	Open Forest	1
	Rainforest	1
	Semi-evergreen vine thicket	1
	Shrubby forest	1
	Woodland	1
	n/a	1
	No Data	1

Elevation, slope and aspect were analysed by occurrence. Individual WVCs were assessed for these topographic features. The resultant values were tabulated in Microsoft Excel.

3.5.10.2 Weighted Raster Overlay

Weighted raster overlay analysis is the final stage of the predictive model. To assess the influence of additional GIS layers for predicting WVCs, three models were created. The three models created were:

1. 4-Variables (4V)
2. 5-Variables (5V)
3. 6-Varibles (6V)

Refer to appendices I-K for schematics outlining their structure and appendix H for the listing of their reclassification weights and raster overlay influence weights.

The 5V and 6V models contain additional layers to the 4V model. The additional layer in the 5V model is the DCDB. The additional layers in the 6V model are the DCDB & aspect.

The initial weighted overlay (4V) utilised 4 datasets in the analysis;

1. Foliage Projective Cover
2. Remnant Vegetation
3. Land Use
4. District Zones

The selection of these 4 datasets for the overlay process was based on their relationship to natural features and/or land use that directly affects natural features.

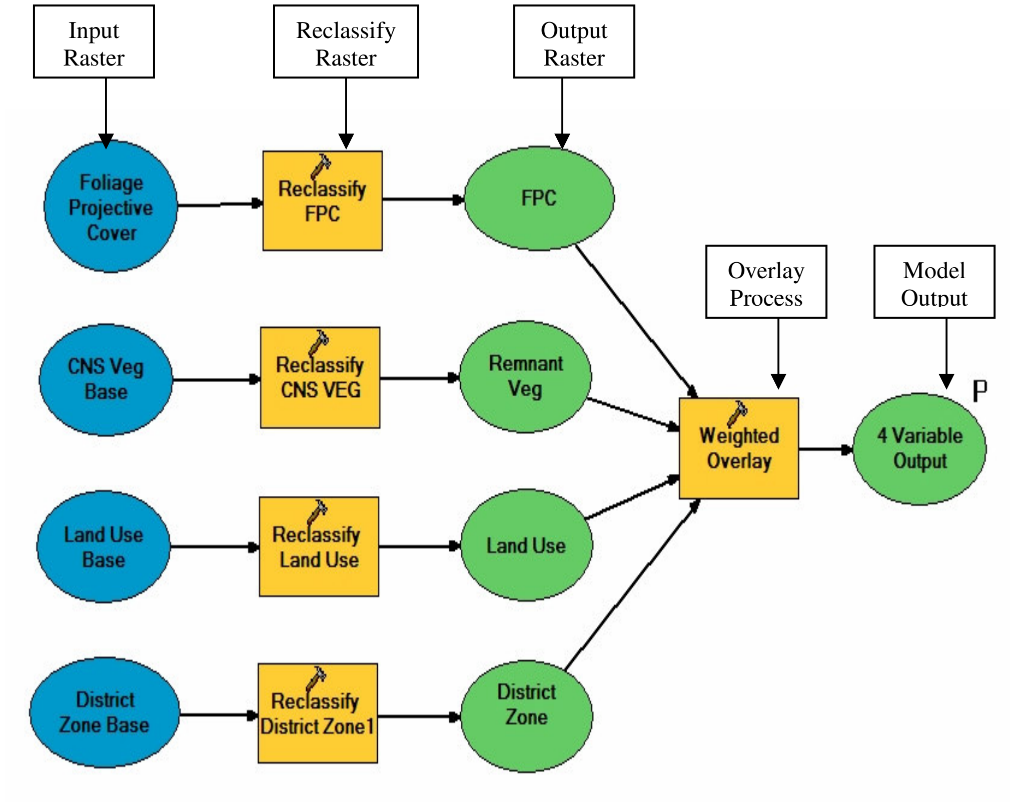

Figure 15. 4 variable MODEL

The schematic above (Figure 15) was produced from ArcMap's ModelBuilder. The first column represents the input raster datasets that were obtained from the relevant data custodians. These datasets are reclassified using the procedures described in section 3.5.10.1. The reclassified output rasters are then overlayed to produce the final raster image. The output raster represents the predictive model output levels of predicted risk of WVC occurrence.

Figure 16 represents a simplified version of the overlay process. INRAS 1 and INRAS 2 represent input rasters for the overlay process. The influence (%) is the raster weight or the weighted importance that the raster layer possesses in the overlay process. The OUTRAS represents the output raster or the predictive model result.

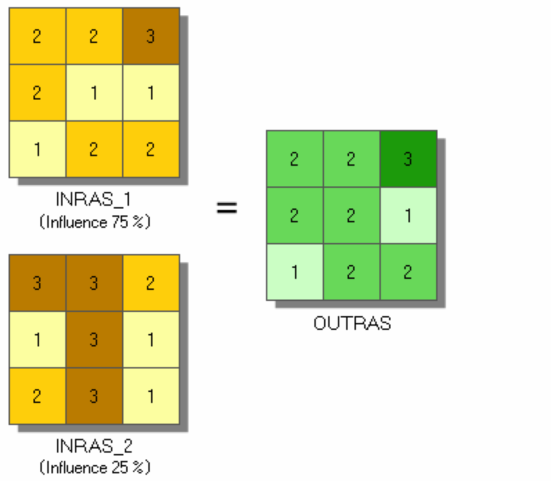

Figure 16. Raster overlay (source: ESRI help)

The reclassification and overlay influence on datasets has a considerable effect on the outcome of the predictive model. Analysis and justification of the process requires much consideration. The justification for this process will be discussed in greater detail in subsequent chapters.

3.5.11 WVC Model Validation

To assess the predictive model output, analysis of the risk categories was undertaken. The locations of surveyed WVCs need to correlate spatially with the determined risk category areas if the overlay process is to be deemed successful.

To determine the relationship between WVCs and the risk category areas, landscape variable extraction and landscape variable analysis was used. These methods were previously described in sections 3.5.5 and 3.5.6 respectively.

Chapter 4 Results

4.1 Pilot Study

4.1.1 GPS Spatial Accuracy

The spatial basis of this project required assessment of the adopted measurement hardware. The Garmin GPS60 used within this project met the positional accuracy benchmark. The level of spatial analysis to be undertaken and the accuracies of the underlying GIS datasets being assessed defined this benchmark.

Table 5 outlines the accuracies achieved by the Garmin GPS60 in the adverse field condition test.

Table 5. Garmin GPS60 logged coordinates

Way Pt	Date	Easting	Northing	Elevation
1	1-Apr-07	397034	6954262	634
2	1-Apr-07	397036	6954256	636
3	1-Apr-07	397032	6954260	635
4	1-Apr-07	397033	6954260	631
5	2-Apr-07	397036	6954259	621
6	2-Apr-07	397033	6954259	635
7	2-Apr-07	397033	6954261	640
8	4-Apr-07	397032	6954258	629
9	4-Apr-07	397033	6954259	629
10	4-Apr-07	397032	6954256	629
11	5-Apr-07	397029	6954256	632
	Mean	397033	6954259	632
	Std Dev	1.9494	2.05396	5.009083

Over the 4 days horizontal position accuracy was better than +/- 5m, with a standard deviation of approximately 2m. While this assessment was not comprehensive, it demonstrates that the GPS unit should achieve spatial accuracies greater than that of the GIS datasets being analysed.

4.1.3 GPS Datum Assessment

Comparison between the GPS's derived coordinates for PSM No.104955 and those noted on the registered Form 6 (see appendix L) within the Department of Natural Resources and Water ensured accurate datum definition. The resultant variation for both horizontal and vertical positions of less than +/- 5 metres between the observed and registered coordinates ensure the Garmin GPS was adequate for this project.

4.1.4 Preliminary Pilot Study Analysis

The pilot study recorded 22 WVCs. Figure 17 shows the percentage land cover by type along the study road at these 22 WVC (combined) locations, at varying buffer radii (WVC 500, WVC 200) as well as for the site corridor (Site 500, Site 200).

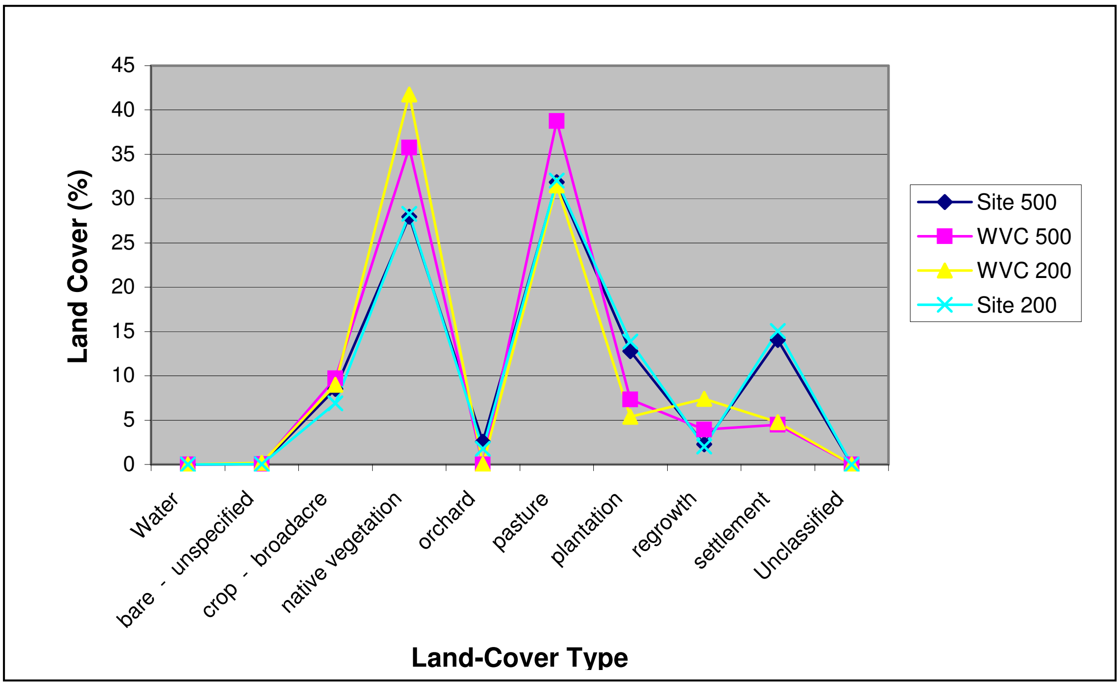

Fig.17. WVC correlations to percent land cover over study site.

There appears to be a correlation between native vegetation and WVCs (Fig.17). Native vegetation occurs more frequently at the combined WVC locations than along the site corridor and also shows the greatest percentage difference of all the land cover types. The reverse can be seen for settlement areas, with the site corridor having a significantly higher percentage than that of the WVCs.

Reduced radii at WVCs increase the percentage of native vegetation from 36% at R500 to 42% at R200. It is believed that this trend would continue at even further reduced radii as, for example, the road reserve (approx 40m) contains significant vegetation.

The occurrence of WVC is also greatly reduced in highly modified landscapes such as those with high percentages of orchards, plantations and settlements.

The analysis of landscape variables at multiple spatial scales was believed to be overly complicated and outside the scope of this project. A 200m offset was therefore selected for the analysis of landscape variables for the remainder of the project.

4.2 Field Methods

This project has created an efficient and robust system for the mapping of WVCs. The use of hand-held GPS and digital photography for the location and identification of WVCs has been an effective mapping system that can be used by a wide range of stakeholders.

Digital photographs have increased the WVC dataset value with additional information being available for other professionals. The ability to identify fauna to species level from the photography provides greater information for possible end users.

The vehicle based survey technique has been efficient for commuting the 50-kilometre survey route circuit. Issues relating to other road users and safety have however been identified.

4.3 Major Survey Results

12 field surveys were conducted over a 6-week period, during which 43 WVCs were recorded and subsequently used for analysis. The following animals were identified over the survey period and recorded under the following 7 categories:

1. Northern Brown Bandicoot (*Isoodon macrourus*)
2. Brushtail Possum (*Trichosurus vulpecula*)
3. Ringtail Possum (*Pseudocheirus peregrinus*)
4. Kangaroo (*Macropus* sp.)
5. Wallaby (*Wallabia bicolour and Macropus* sp.)
6. Hare (*Lepus europeaus*)
7. Unknown (unidentifiable due to age or condition)

A complete list of located WVCs, their coordinates and associated photograph numbers can be found in Appendix F. The WVCs identified represent mainly medium sized mammals. The non-representation of smaller species will be discussed in Chapter 5.

4.4 Landscape Analysis

4.4.1 District Zones

Figure 18 shows the landscape variable analysis of district zones for both WVCs and the site corridor.

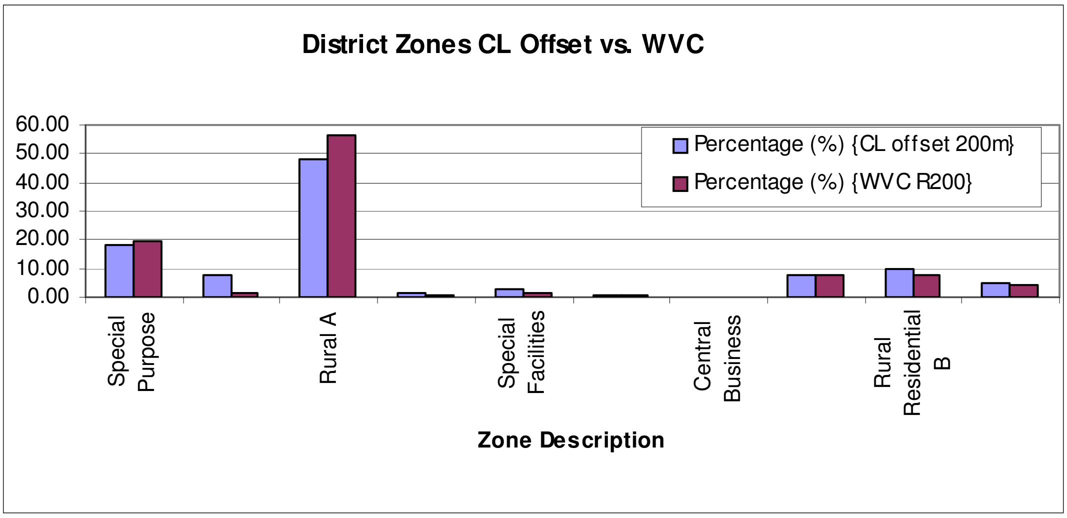

Fig.18. Landscape variable District Zones

Zones that represent non-residential and commercial land uses correlate with the occurrence of WVCs. Rural A and special purposes were the most predominant district zones within the dataset. Rural A shows the greatest difference between the WVC positions and the site corridor

4.4.2 Foliage Projective Cover (FPC)

FPC analysis demonstrated that Open Forests were the most predominant foliage description within this dataset. Figure 19 shows the relationship of WVCs to FPC and the variation to the site corridor.

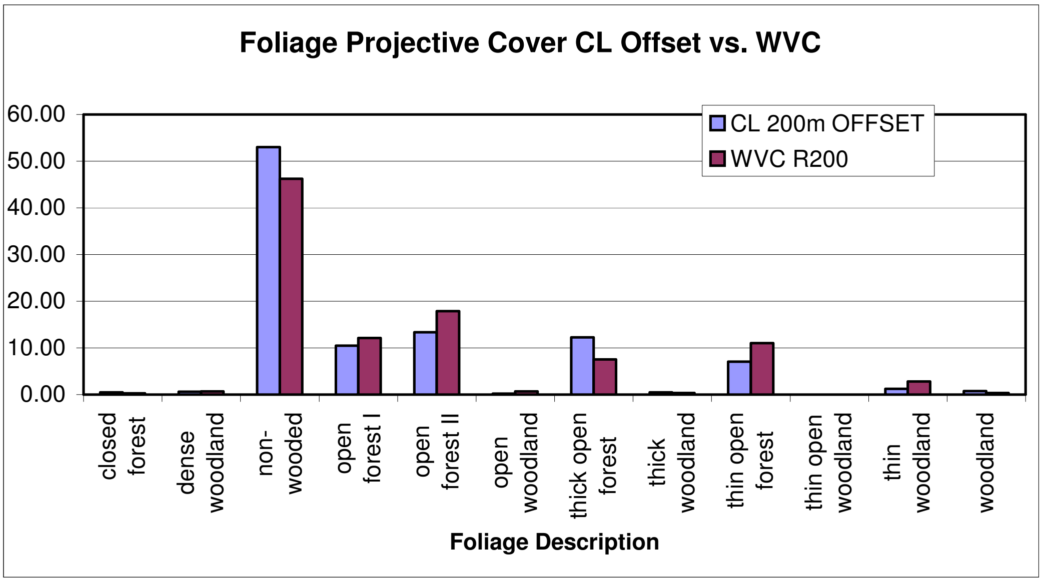

Fig.19. Landscape variable Foliage Projective Cover

Although 'non-wooded' occurs frequently in the WVC dataset, it was not considered important because it occurs more frequently along the entire site corridor.

4.4.3 Digital Cadastral Database (DCDB)

The DCDB was analysed as a frequency of lot size occurrence. Figure 20 shows the percentage of lots (defined by their area) found within the site corridor and within the WVC buffer areas.

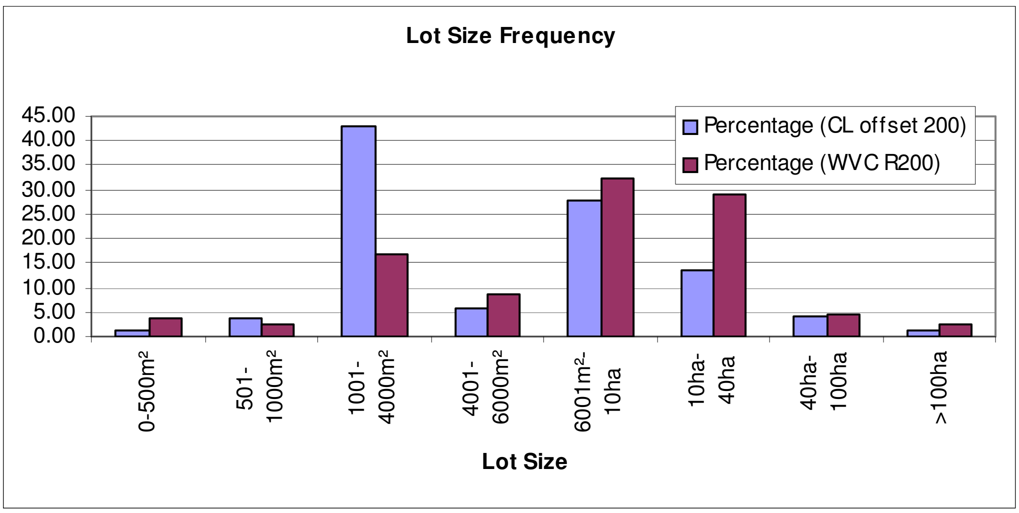

Fig.20. Landscape variable DCDB by Lot size frequency

WVCs occur more frequently when the lot size is greater than 4000m². This result may correlate with the district zones dataset, with rural areas being more represented at WVC locations.

4.4.4 Land Use

Land use analysis found that native vegetation and regrowth were the most significant land use types related to WVCs. Figure 21 shows the percentage occurrence of land use types.

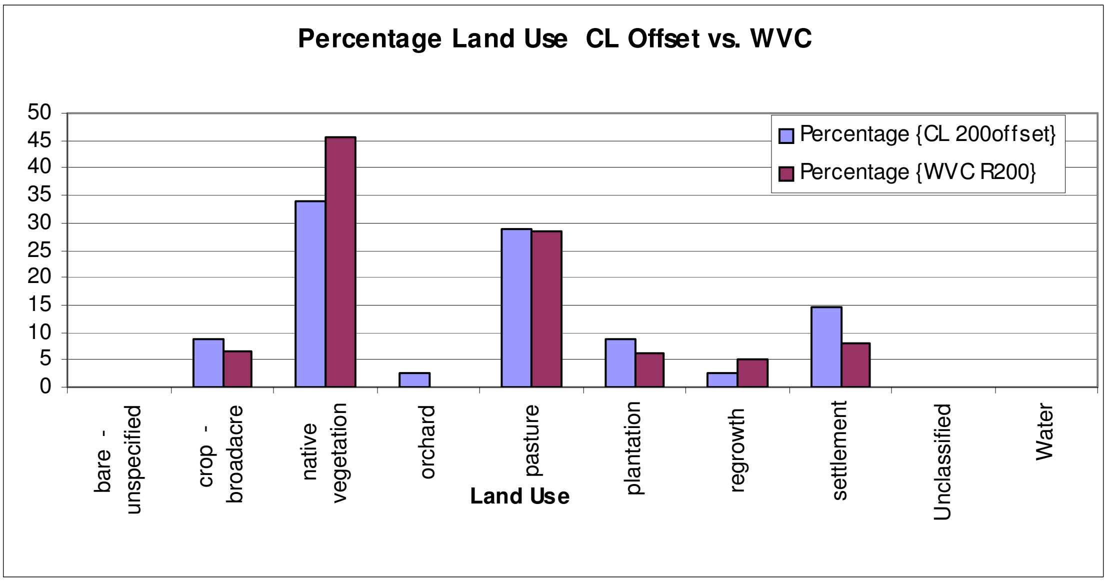

Fig.21. Landscape variable Land Use

The results of this analysis are consistent with the initial pilot study analysis. Native vegetation and regrowth show the greatest positive percent cover differences between the WVC locations and the site corridor.

4.4.5 Remnant Vegetation

Figure 22 shows the percentage of remnant vegetation classifications that occur within the site corridor and within the WVC buffer areas.

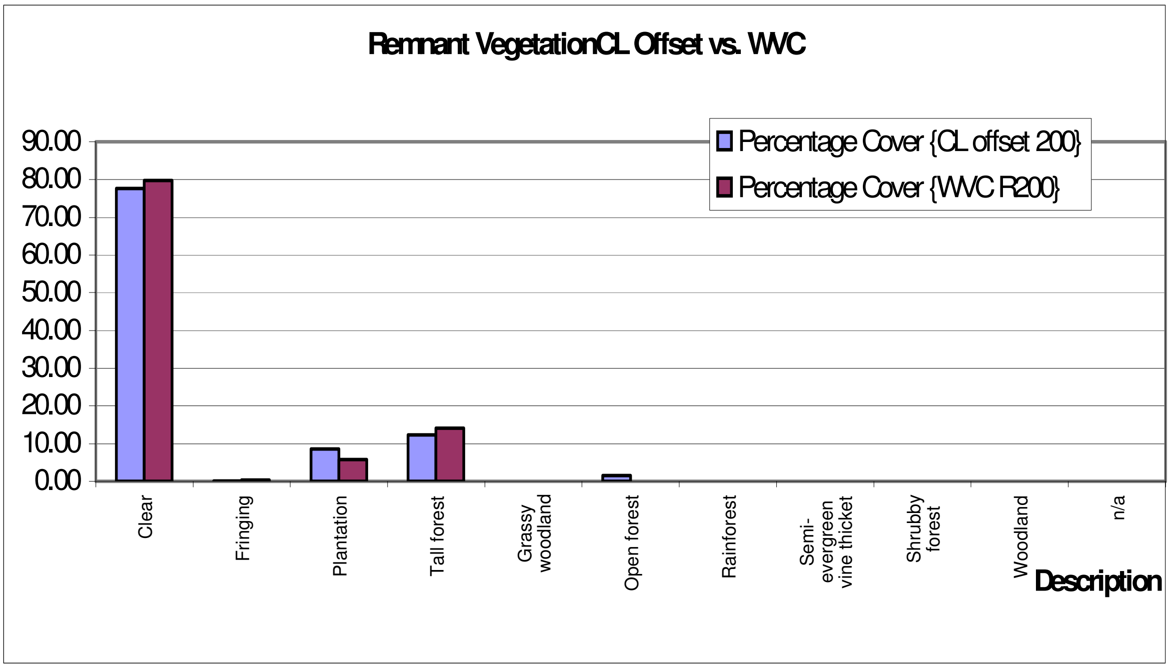

Fig.22. Landscape variable Remnant Vegetation

Clear areas occur very commonly along the entire site corridor, although slightly more often at WVC locations. Tall forest is also represented more at WVC locations than the site corridor.

4.4 Cluster Analysis

Figure 23 displays the number of WVCs that occurred in each 200-metre interval of the survey route. Several potential WVC clusters are visible. Areas where no WVCs occur are also obvious (null areas).

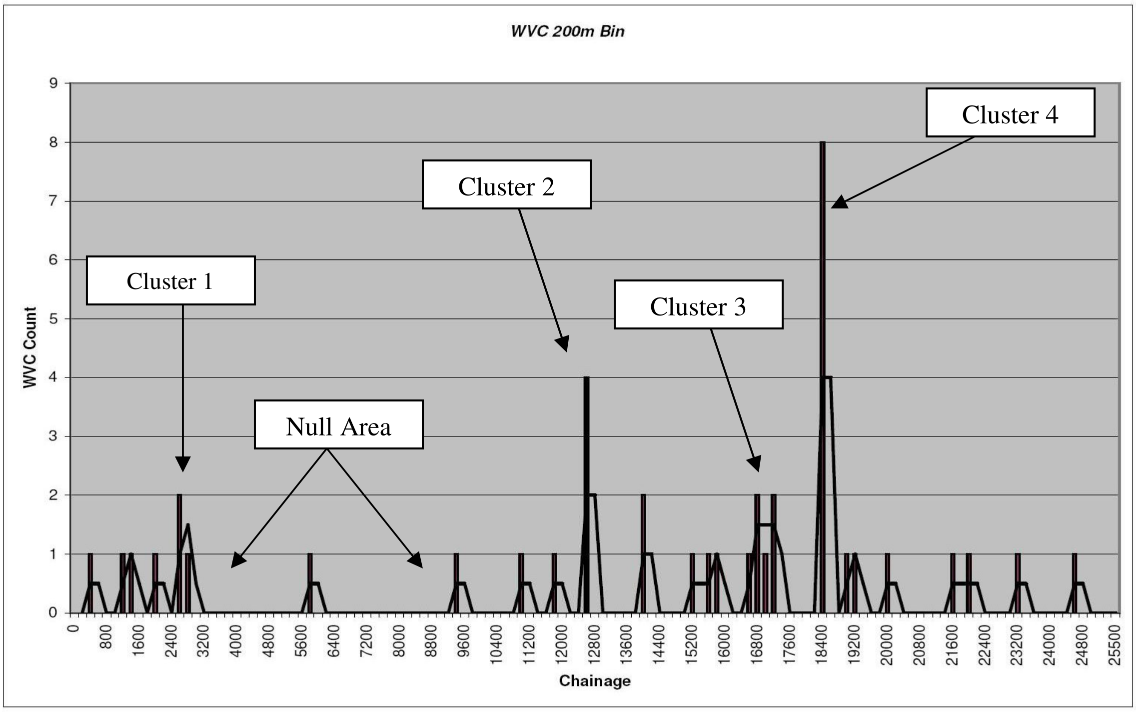

Fig.23. WVC frequency at 200m intervals

Cluster 1 occurs between Toowoomba and Highfields. There is a distinct null area between chainages 3200 and 9000, which appears to be associated with Highfields, and land uses adjoining Highfields. The determination of clusters has not been statistically tested. These potential clusters will be discussed in greater detail in the following chapter.

4.5 Digital Elevation Model

4.5.1 Elevation

All WVC elevations can be found in Appendix F. The elevations recorded from the WVC locations were representative of the entire survey route (appendix M). The value in using elevation within the analysis was therefore considered limited. Elevation was subsequently not utilised for WVC modelling within this project.

4.5.2 Slope

Individual WVC positions were assessed for their topographic slope. Figure 24 represents the WVC frequencies within a given slope range. The proportion of frequency within the given slope ranges is considered consistent with that occurring along the site corridor (Appendix N). Therefore no further analysis on slopes occurred and the variable was not used for any further analysis.

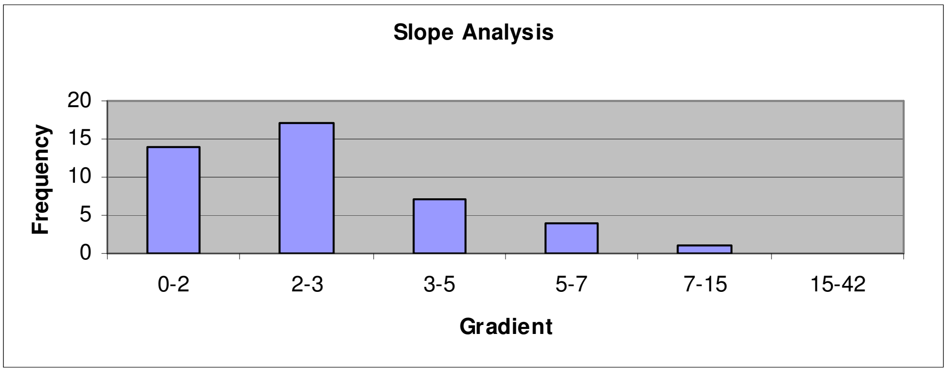

Fig.24. Landscape variable Topographic Slope

4.5.3 Aspect

Aspect was extracted from the DEM at each WVC location. From Figure 25 it can be seen that WVCs occurred more frequently on northerly and westerly aspects.

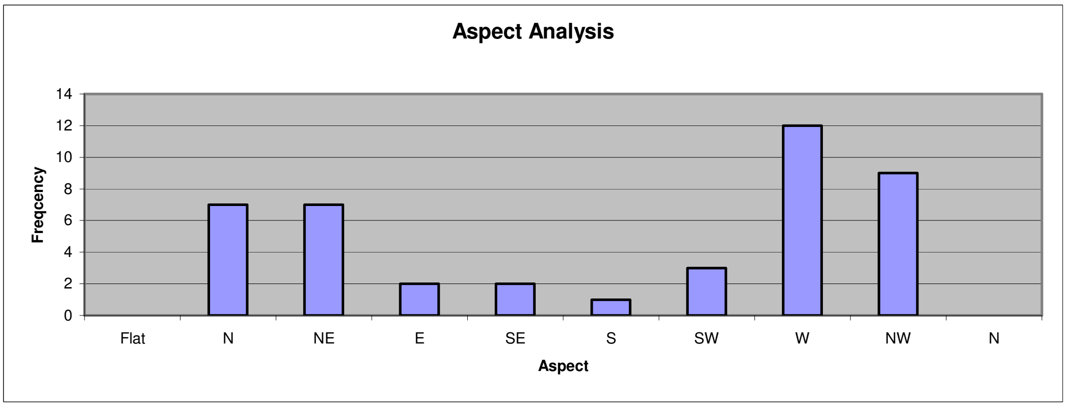

Fig.25. Landscape variable Topographic Aspect

The NE, N, NW & W aspects correlate with WVC locations and were assigned greater importance within the predictive model (Appendix O).

4.6 Predictive Models

The use of ArcMap to develop predictive models has been successful. The predictive models are an effective means for displaying WVC risk areas. Three overlay predictive models were created (4V, 5V & 6V). Figures 26 - 28 display the weighted raster overlay output models that have been developed.

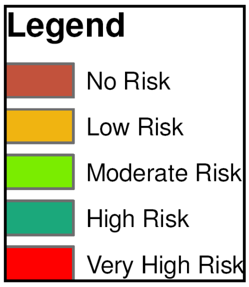

Fig.26. Risk Category Legend

To distinguish the risk categories predominant colours were used (Fig.26). Areas associated with a very high risk of WVC are red, high risk areas are dark green, moderate risk areas are light green, low risk areas are light brown and no risk areas are dark brown. The classification of risk category names has been assumed. Significant research needs to be undertaken to define these risk classification.

The model outputs display distinct relationships to the surrounding environments. Remnant vegetation areas are predominantly associated with high and very high risk areas. Land use zones and the DCDB influence the model with abrupt classification changes along cadastral boundaries.

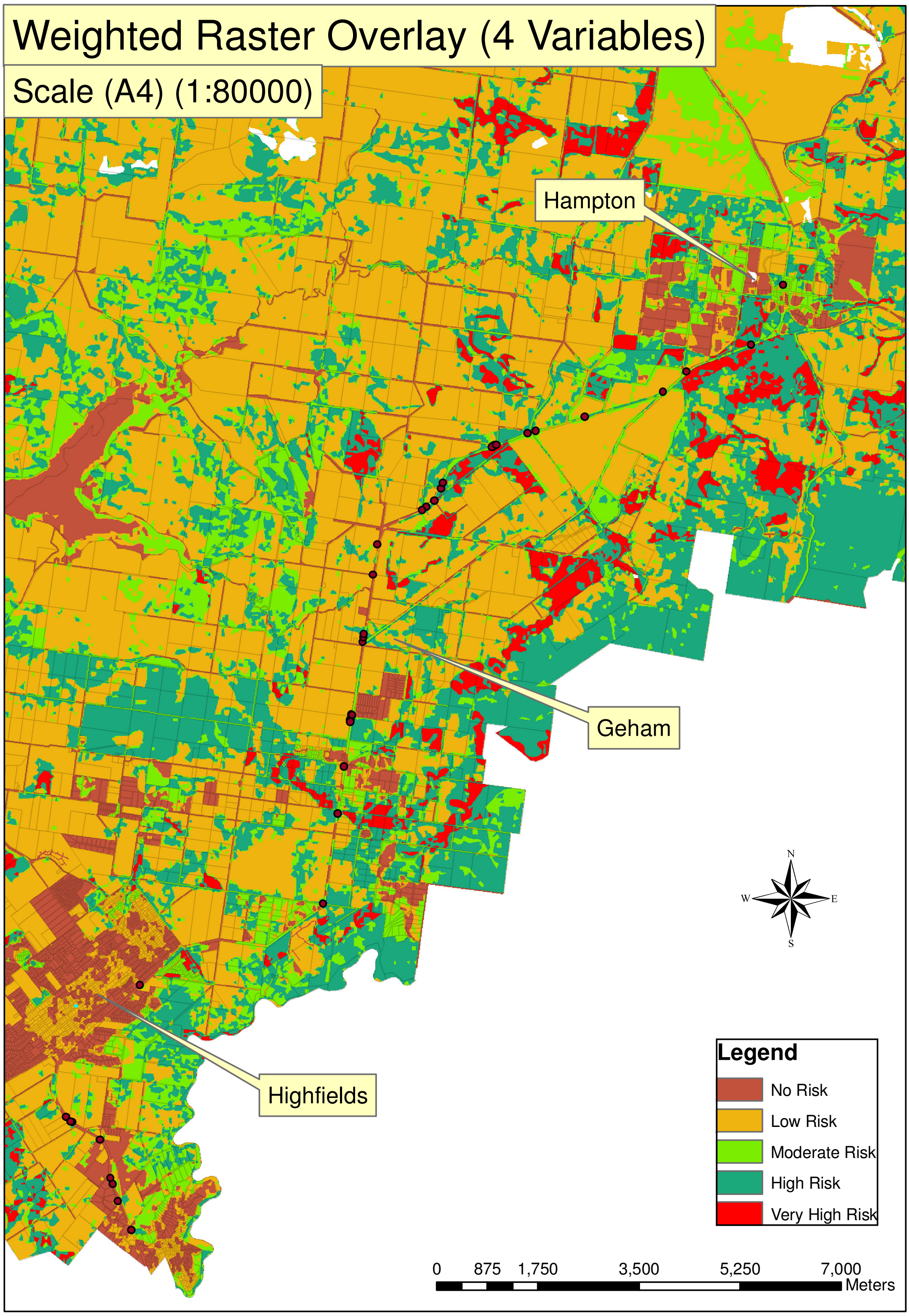

Fig.27. Predictive Model (4V) 4 Variables

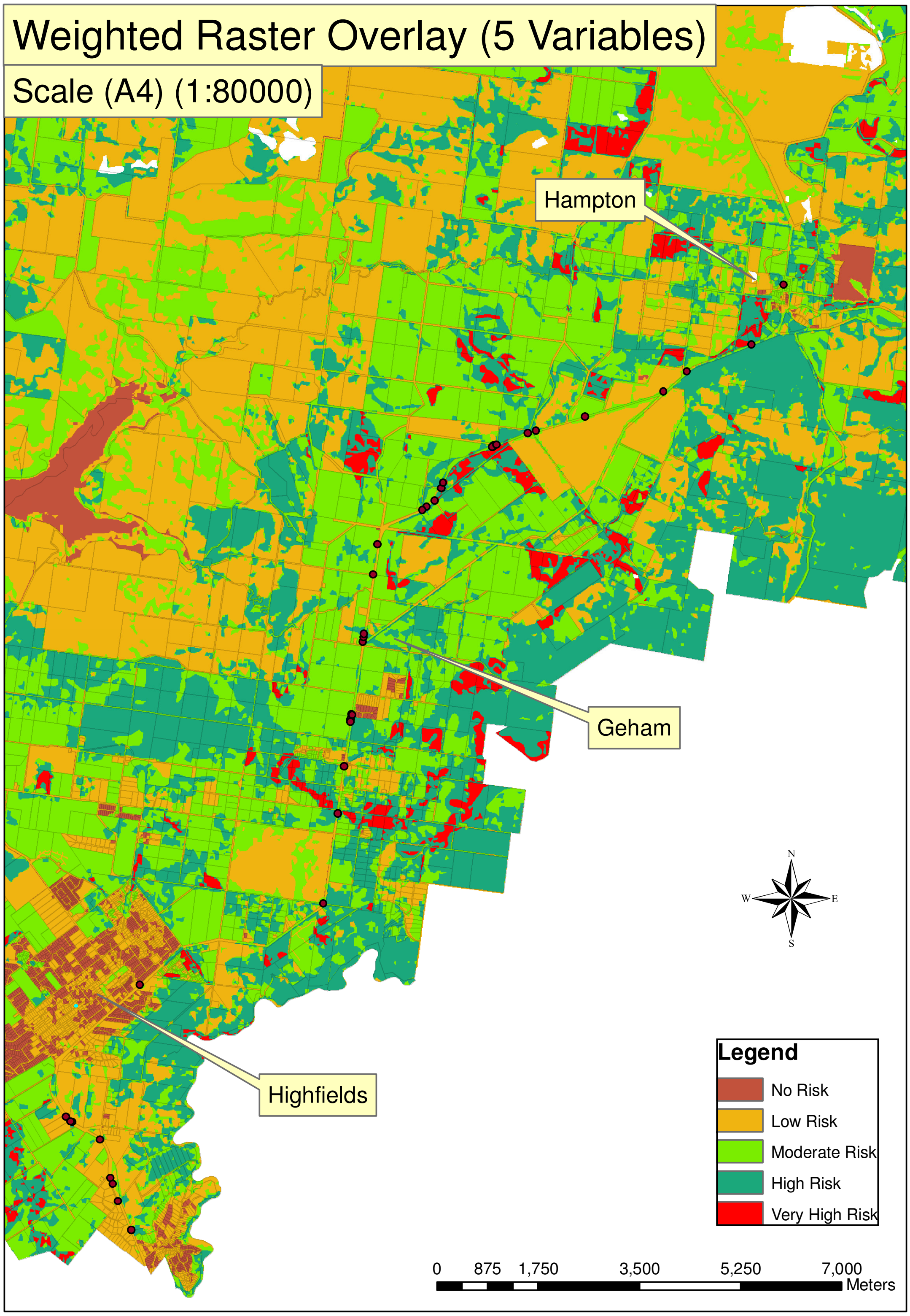

Fig.28. Predictive Model (5V) 5 Variables

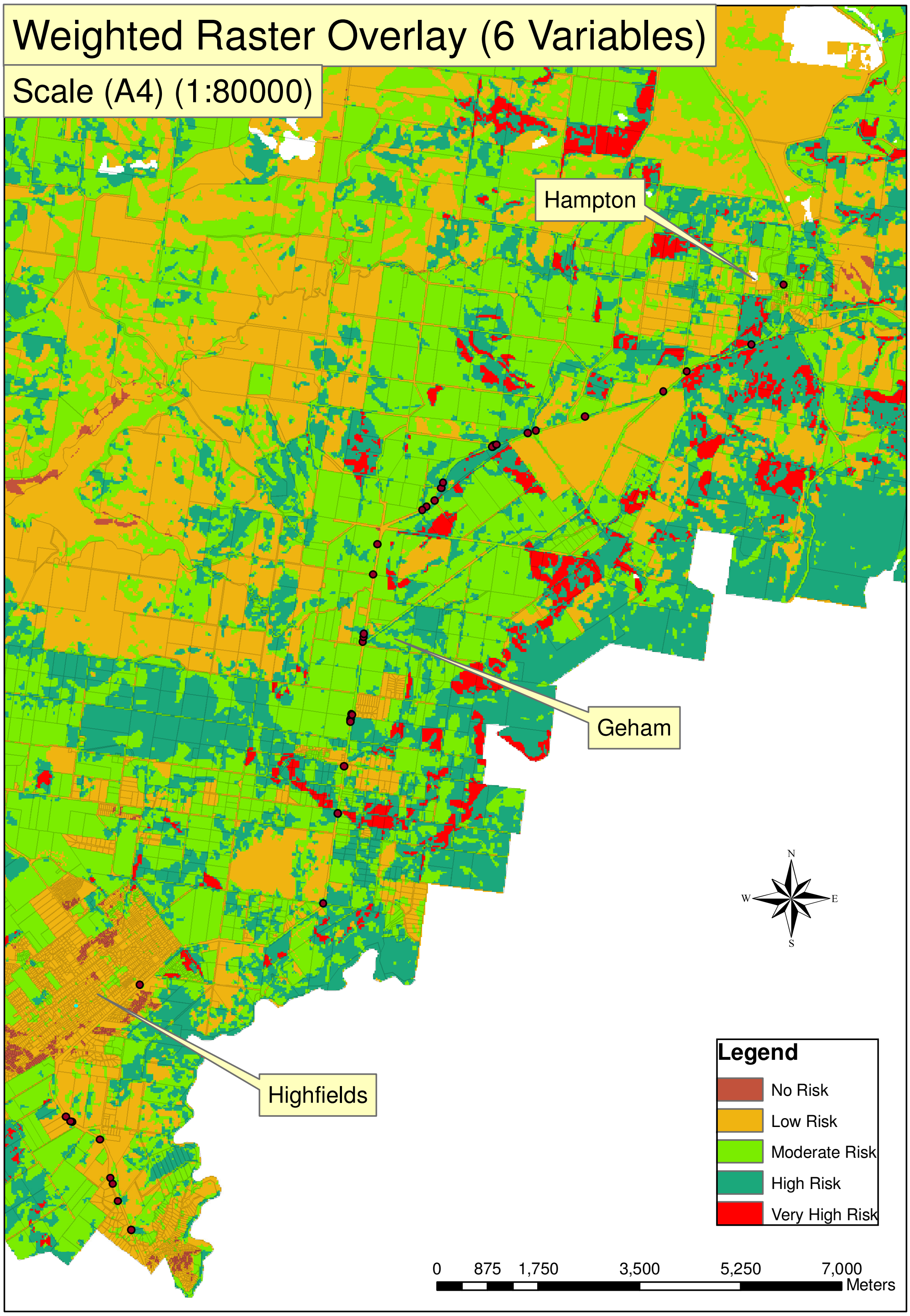

Fig.29. Predictive Model (6V) 6 Variables

Appendices P1-P5 show WVC locations along the survey route overlayed on satellite imagery. These figures allow an appreciation of the real landscape features, as opposed to GIS datasets.

4.7 Model Validation

The effectiveness of each of these models was assessed with respect to reclassification and overlay weights. Table 6 outlines the occurrence of risk categories produced by the 3 different models for individual WVCs and the site corridor.

Table 6. Risk category assessment

	WVC (4V)	WVC (5V)	WVC (6V)	Site Corridor (4V)	Site Corridor (5V)	Site Corridor (6V)
No Risk	14%	2%	0%	19%	5%	1%
Low Risk	37%	29%	27%	44%	35%	37%
Moderate Risk	20%	38%	42%	17%	38%	41%
High Risk	21%	23%	27%	15%	20%	19%
Very High Risk	8%	7%	4%	4%	2%	3%

Plotting the risk categories for the individual WVCs and the Site Corridor demonstrates the effectiveness of the reclassification and weighted overlay process. Figure 30 shows that for each of the three models, WVCs are more associated with categories higher than "moderate risk" in comparison to their corresponding site corridor.

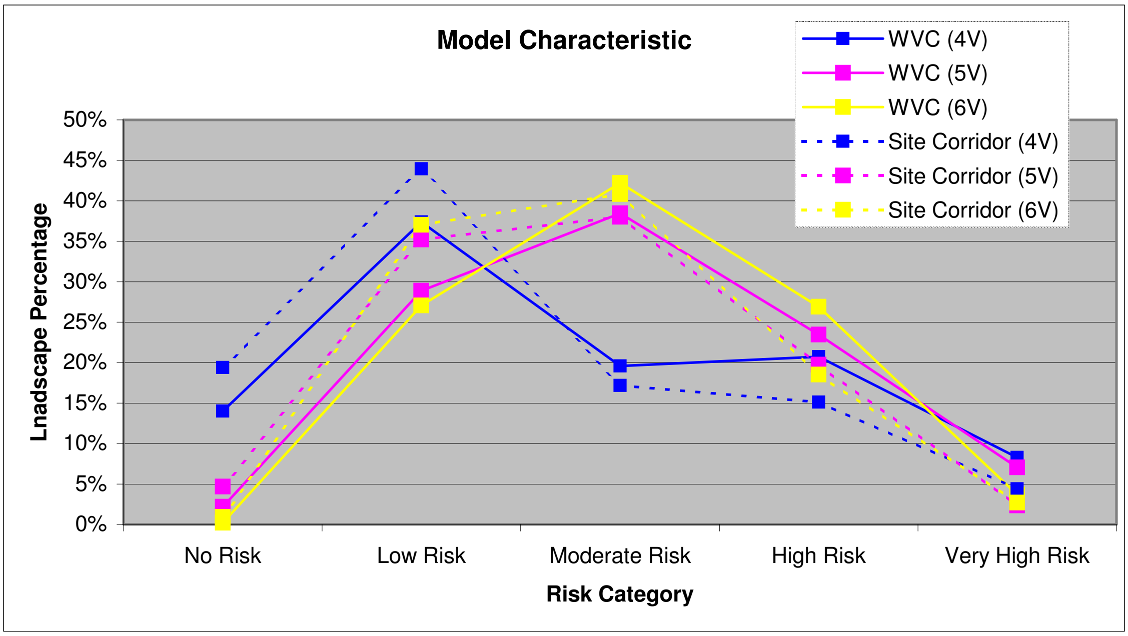

Fig.30. Risk category (WVC vs. Site Corridor)

Chapter 5 Discussion

5.1 Pilot Study

Conducting a pilot study proved an effective approach to develop a comprehensive mapping system to achieve the projects desired goals for the mapping of WVCs. The development of methods within the pilot study ensured success for the final project.

5.1.1 GPS Spatial accuracy and datum assessment

A quality assurance check on a coordinated survey mark is an effective way to ensure there are no coordinate datum variations between WVC survey data and GIS datasets. This process should be followed when any form of GPS mapping is to be undertaken. It would be wise for future WVC studies to locate a known position at the start and finish of each survey. This would ensure that the GPS datum configuration did not change over the period and if selective availability is occurring.

The spatial accuracy of GIS base-data varies considerably within and between individual datasets. From the dataset metadata it was established that the average spatial accuracy for all datasets analysed was approximately +/- 25m. The Garmin Handheld GPS has a manufacturers accuracy of +/- 15m with selected availability turned off. After testing, the GPS showed a higher accuracy than that prescribed by the manufacturer. The use of handheld GPS for the location of WVCs is therefore effective because it has a higher positional accuracy than the base GIS data. GPS logged positions from inside a moving vehicle however would be susceptible to lag periods and lower GPS signal accuracy. This technique could result in WVCs being incorrectly positioned by considerable distances. Therefore it is necessary to always stop and record the WVC location from outside the vehicle.

5.1.2 Multiple spatial scale analysis

The pilot study analysis investigated landscape variation at different spatial scales (200 & 500m offset). Variations in landscape descriptions at multiple scales did occur for WVC locations. Multiple spatial scale analysis at surveyed WVC locations could be of greater significance than that of the site corridor. Percent variation in remnant vegetation (Fig. 38) between the WVC 200 (42%) and WVC 500 (36%) demonstrates increased fauna services closer to the road. It is expected that this percentage would increase at further reduced radii due to the vegetated road reserve.

The reverse occurs for pasture with WVC 500 (39%) and WVC 200 at (31%). The increased percentage of pasture in WVC 500 supports the finding of a higher percentage of remnant vegetation in the WVC 200 corridor (compared with WVC 500).

Conducting analysis at different scales could help predict the importance of a particular location and how it relates to the surrounding landscape, as opposed to the direct overlay of landscape attributes. The following example demonstrates this theory:

1. R1000 - 75% Remnant Vegetation
2. R500 - 35% Remnant Vegetation
3. R200 - 20% Remnant Vegetation
4. R50 - 2% Remnant Vegetation

From the fabricated data above it can be seen that the road reserve (R50) contains limited remnant vegetation (2%). If the analysis only occurred at radii greater than 200m the location may appear as a high risk WVC location. However, the actual risk for this location may be much lower, as analysis at radii less than 200m would show the area closer to the road is relatively denude of remnant vegetation.

The reverse could also occur with larger radii analysis defining a position as lacking remnant vegetation, yet the road reserve at a width of 50m provides enough habitat to maintain animal movements or local populations.

Analysis at multiple spatial scales was not conducted in the main study because of the great complexity involved. It may however provide necessary information on landscape attributes that govern the presence or absence of an animal within a road reserve. Animals may be present due to either food or nesting resources within the actual road reserve, or due to larger scale movements between habitat areas that the road bisects (Bellamy et al. 2000). Therefore multiple spatial scales should be considered when assessing risk of WVCs.

5.2 Mapping & field survey protocols

5.2.1 GIS data and software

A multitude of GIS software packages are available. The functions available in each software package vary considerably. Variation within a particular package can also occur, for example within ArcMap you require extensions to enable certain types of analysis. The functionality of available software needs to be considered before attempting this type of research.

Data acquisition has been a major component of this project. GIS datasets have shown to be accessible when a project is for educational, environmental and non-profit research. To undertake this research as a private consultant would significantly increase costs associated with GIS data acquisition.

Further, good communication skills are required when sourcing GIS data from relevant authorities. The importance and relevance of the research project has to be outlined to data custodians. Contact with authorities requires persistence and determination to achieve the data acquisition objective.

Data formats should always be considered when obtaining GIS datasets. Considerable time was lost in this project through having to convert incompatible data types. When approaching data custodians a researcher should be aware of the formats that their GIS software can import.

5.2.2 GPS hardware

Handheld GPS proved an effective tool for WVC surveys. The inexpensive GPS used for this project was adequate and provided the desired outcomes. However, if funding for this project had been available then a more integrated system could have been sourced. It is believed that the use of a modern palm computer that has incorporated GPS, photographic and databasing capabilities could greatly improve the surveys efficiency and integrity.

5.2.3 Survey Site Selection

Ecosystem characteristics along the survey route are important. The road corridor surveyed in this project had similar ecosystem characteristics along the entire route. This consistency allowed direct comparisons of WVCs to the entire site corridor. If a road traversed several ecosystem types (for example high altitude closed forest to Downs open grassland) consistency would be lost, with the landscape attributes important to the associated fauna changing. It is therefore believed that study areas chosen to be modelled for this type of research should be contained within the one ecosystem type.

5.2.4 Survey Technique

The survey technique being employed is dependent on the fauna being surveyed and the distance being traversed. The vehicle-based technique used for this survey was successful in identifying medium and large mammals, and large birds and reptiles. The lack of small mammals such as rodents being present in the survey data may suggest that this technique has limits. Taylor & Goldingay (2003; 2004) found similar results in their research when conducted by vehicle-based survey.

To survey the entire species range affected by roads it would be necessary to reduce the vehicles speed considerably. The use of a bicycle could be beneficial if the survey route was short enough and safe for pedestrians.

During the vehicle survey it was noted that traversing the route at 40kmph below the legal speed limit tended to irritate other road users. Their subsequent actions of over-taking or tailgating were recognised as a significant safety issue.

Various safety strategies were identified that should be adopted for all similar surveys:

- The use of vehicle mounted flashing lights
- Rear mount sign identifying that a survey is being conducted
- Team members wearing high visibility vest both inside and outside the vehicle
- Allowing vehicles to pass before the user becomes irritated
- Undertaking the surveys in non peak-hour periods

5.2.5 Overall Field Methodologies

The mapping protocols and field methods developed have worked effectively, achieving objectives 1 & 2 of this research project. The use of widely available resources and the pragmatic design should enable non-spatial science professionals to be involved in WVC surveys and predictive modelling. The field mapping system developed could be standardised for use by local/state authorities. This would allow exchange of information and the creation of a large dataset available across management levels. The lack of an augmented WVC database has been acknowledged by Sauter (2006) as hindering research and development in WVC mitigation.

5.3 GIS modelling

Predictive models are completely dependent on the GIS datasets being utilised. Numerous GIS datasets were initially obtained for this project. From those datasets only 6 were considered of value for the overlay process. Additional GIS datasets that contain information relating to roadside palatable vegetation, animal dispersal corridors or permanent water bodies (small dams) may improve the predictive model. However these were not found and are possibly not available. Alternatively, superfluous additional data may also over complicate the model. The most relevant data possible must be used to produce the best model output.

Further, a major component that affects the success of any GIS based modelling relates to the users knowledge. Limited user knowledge of ArcMap has significantly reduced the predictive models development. A large amount of time spent on this project was dedicated to software training as opposed to model development.

5.3.1 Cluster Analysis

WVCs along the survey route occurred both individually and within groups identified as clusters. Equal weighting was given to landscape variables around each WVC, however this should be reviewed. Isolated WVCs should not be given the same weight as WVCs occurring within clusters. The influence of isolated WVCs that are located in low risk areas (eg. urban) could have undue influence on the final reclassification values. The use of statistics to give importance weights to clusters could be of great value.

Kernel density analysis within Spatial Analyst may provide a means of defining the WVC clusters. Ramp et al. (2005) used kernel density analysis to identify WVC clusters in individual species as well as a network-k function to further define those clusters. Research would first have to be undertaken to determine the importance of identified clusters. Once cluster importance has been determined, a scale factor could be applied to the associated landscape variables before their inclusion in the analysis and reclassification processes.

5.3.2 Extracting landscape variables

The buffer and clip analysis process proved highly effective for extracting landscape variables when dealing with single feature elements (individual WVC buffers). The extraction of landscape variables containing overlapping buffer areas proved to be laborious with each WVC buffer having to be assessed individually. No functions within ArcMap were found that could undertake all of these operations simultaneously.

5.3.3 Model success in correlating WVCs to landscape variables

Figure 30 showed that for each of the three models, WVCs are more associated with output categories higher than “moderate risk”. This assessment demonstrated the effectiveness of the reclassification and weighted overlay process to show a correlation of WVCs with landscape variables. Nowhere in the literature assessed has this process been used before to assess wildlife vehicle collisions.

5.3.4 Reclassification values

In the landscape variable extraction process landscape description percentages in the site corridor were compared with landscape description percentages in the WVC buffer areas. However, not all landscape descriptions present across the landscape were present within the site corridor or WVC buffer areas. These descriptions not represented acquired a reclassification value of one (1). This would have reduced the ability of the model output to predict WVC occurrence in areas where these non-represented variables exist. It is believed this would reduce the power of the model to predict high-quality (or "low risk") locations for new roads.

5.3.5 Layer weights

The three models (4V, 5V, 6V) contained 4, 5 and 6 variables respectively. Model 4V and 5V placed equal weighting on each variable because an equal importance was assumed. Model 6V lowered the weighting of the 2 additional variables not included in model 4V. This was because these 2 variables (DCDB and aspect) were considered to be of lower importance.

The appropriateness of the GIS layer weights were not determined in the analysis process and the influence of layer weights needs to be further researched. Further appraisal of existing literature, for example the relative importance of landscape variables for fauna needs, may assist in the assessment of these weights. Likewise, repetition of the model with varying layer weights and analysis of the output model through model validation may emphasize importance of variables.

5.3.6 Model output

The validation of the output model from this project has proven that WVCs can be associated to landscape variables. This result should mean that the location of WVCs could be predicted using landscape variables with the raster overlay process. However, the probable occurrence of WVCs under the assigned 'risk' categories is unknown and further analysis is required. To date no research has occurred within Australia that utilises the weighted raster overlay process to predict the location of WVCs.

The graphical output from the predictive model is clear and easily analysed. The basic colour scheme allows non-professionals to interpret risk categories easily.

Through the use of Model Builder additional datasets can be incorporated and the predictive model is easily manipulated and adjusted to reflect further analysis of landscape variables. The modelling process can be further refined over time with repetitions and analysis of the output.

5.3.7 Model Limitations

While the model output shows correlation with recorded WVCs, it also has limitations. The fact that animals may use areas defined by the output model as "lower risk" for migration, dispersal or home-range movements, limits the ability of raster overlay models to predict the specific occurrence of WVCs.

The broad scale nature of the model developed makes it suitable for testing potential locations of proposed roads as it defines the main landscape attributes associated with WVCs. The use of these model outputs for the location of mitigation strategies along existing roads would however be unwise, as movement paths of fauna, road geometry, traffic volume, barrier effects and vehicle speeds have not been utilised within the analysis. It is believed that such data would add great value to the model output.

A modelling technique has been developed in this project, however it has become evident that the occurrence of WVCs is far too complicated to solely use a GIS raster overlay process to predict their occurrence. For effective mitigation of WVCs the accurate identification of high-risk areas is essential. It would be beneficial to undertake the field survey described in this paper in conjunction with cluster analysis to locate the occurrence of WVCs and define the best location for mitigation strategies.

5.4 Road users and road characteristics

Previous research has shown that WVCs have a direct correlation with road design, geometry and maintenance (Magnus 2006). Although this project did not investigate these relationships it was observed that road geometry in particular may have had an influence on the occurrence and location of WVCs. Appendix Q1 displays the location of cluster 3. This cluster represents 14% of the total surveyed WVCs. Although the region contains a high level of risk as defined by the predictive model, it is believed that a major factor of the WVC occurrences may relate to road geometry. This particular section of road contains an overtaking lane for outbound traffic, a sweeping horizontal bend and a steep vertical curve as the highway climbs past the Geham Dump. Magnus (2006) identified that sight distances and vehicle speeds increase the occurrence of WVCs. It appears that cluster 3 may be strongly associated with reduced sight distances and increased vehicle speeds as users approach the incline.

Analysis of traffic volume and commuter time periods was not undertaken in this study. However, it was observed that approximately 70% of all WVCs occurred on the outbound side of the road reserve. Commuters travelling from Toowoomba during evening periods may therefore coincide with wildlife movements and hence the increased occurrence of WVCs. It could be worthwhile to look into this observation.

5.5 Other factors

5.5.1 Environmental factors

The WVC survey was conducted during a severe drought. Klocker et al. (2006) suggested that the effects of very dry conditions, for example reduced foliage cover, may influence WVC numbers and locations. It is unknown as to whether WVC numbers would increase or decrease over the survey route if climatic conditions changed. Having commuted the survey route over several years it has been noted that seasonal variation does appear to coincide with WVC numbers (unpub. data). Further research over an extended period of time is required to account for seasonal variation, including the effects of drought.

Coulson (1982) found the lunar cycle effected WVC survey numbers. The survey period in this study was long enough to account for the full lunar cycle (AstroNet 2007). Therefore moon phases should have had no influence on the WVC data.

5.5.2 WVC survey technique

The vehicle based survey technique appears to have had limited success in identifying smaller types of fauna. Taylor & Goldingay (2003; 2004) suggested that the absence of smaller species in their sample data implied limitations in their survey method rather than the absence of those species along the survey route. Their vehicle-based survey utilised an average speed of 70-80kmph. In comparison this project adopted a maximum vehicle speed of 60kmph. Even with the reduced vehicle speed smaller species were not identified. It is not known whether the absence of smaller mammals is due to the survey technique or just the absence of those species over the survey route.

5.5.3 Landscape geometry

The configuration of landscape variables has an impact on fauna. Vegetation patch size, shape and structure determine its usability to fauna. Bowman et al. (2002) identified that patch size and shape relate to fauna movement. Landscape relationships between variables also impacts on the ability of fauna to migrate, disperse and carry out daily movements. To develop a technique within ArcMap that determines these relationships would be of great benefit to the predictive model. Euclidean distance analysis provides a simplified means of buffering identified regions within the landscape. However, it was found that this process does not identify the potential connectivity between patches and therefore possible movement corridors.

5.6 The survey route, WVC occurrences & assessed data layers

To outline the complexity of WVC predictive modelling the location of WVCs along the entire survey route will be discussed. The use of satellite imagery was useful to visualise the landscape surrounding WVCs.

Appendix P1 shows a clustered occurrence of Northern Brown Bandicoots (cluster 1) (Refer Fig.23). WVCs 1, 20 & 21 are located beside a small patch of vegetation, but are also located in an agricultural landscape with large areas of grassland. Their occurrence may relate to the presence of open grassland as bandicoots are known to utilise open areas for foraging (Chambers & Dickman 2002). The grouping of species within a small area should be considered significant and gain an increased weighting for landscapes variable within the overlay analysis. This also highlights the need to model species with different requirements separately.

Different species have different resource and movement requirements. This fact could create problems with analysing multiple species together. For example, Bandicoots will use open areas at night as opposed to other fauna that may migrate during daylight hours. Macropods move much larger distances than smaller species such as Bandicoots. Possums can exist in highly modified landscapes. Including all the species in the same analysis could reduce the accuracy of the model by cancelling each other out.

Appendix P2 (Map 2) may be displaying the impact of an urban environment on fauna. The only recorded WVC within this section was a Ringtail Possum. Possums are known for their ability to persist within urban environments (Brady 2007unpub. data).

Appendix P3 (Map 3) shows only one WVC occurring in the entire section of road. It is unclear as to why WVCs do not occur in this section of the survey route. Possible reasons may include the influence of land uses and barriers to animal movement. The areas of cultivation and urbanisation may provide limited fauna services and therefore animals do not have a need to cross the NEH to these areas (from native vegetation on the southeast side of the NEH). Fauna movement is most likely associated with the escarpment. Animals may instead be dispersing along the vegetated areas parallel to the NEH in the southeast corner of the map. The NEH on Map 3 contains a large section of guardrail that may pose access problems for fauna. The military base at Barracks Road also has fauna proof fencing around its perimeter creating a significant barrier affect.

Appendix P4 (Map 4) shows a significant increase in WVC numbers in this section of the NEH, including the potential 'cluster 2' (Fig.23). This could be due to the presence of a dispersal corridor crossing the highway where a funnelling effect of surrounding rural-residential land uses may be occurring (Figures 31 & 32). This section of the NEH may also have increased vehicle speeds (pers.obs.).

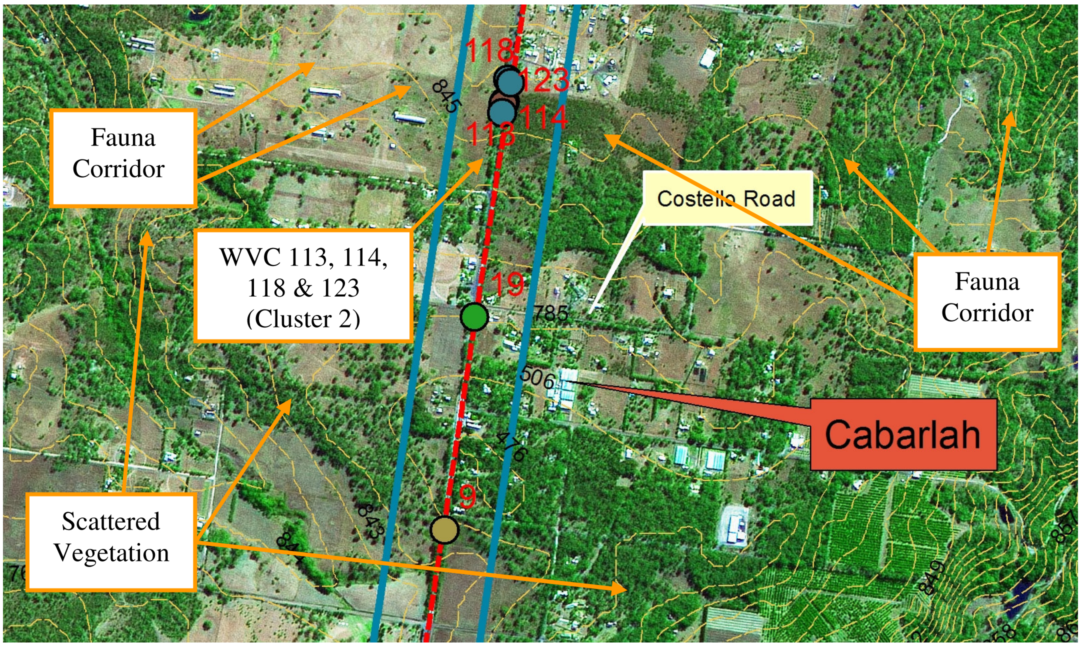

Figure 31. Cluster 2 and satellite image background

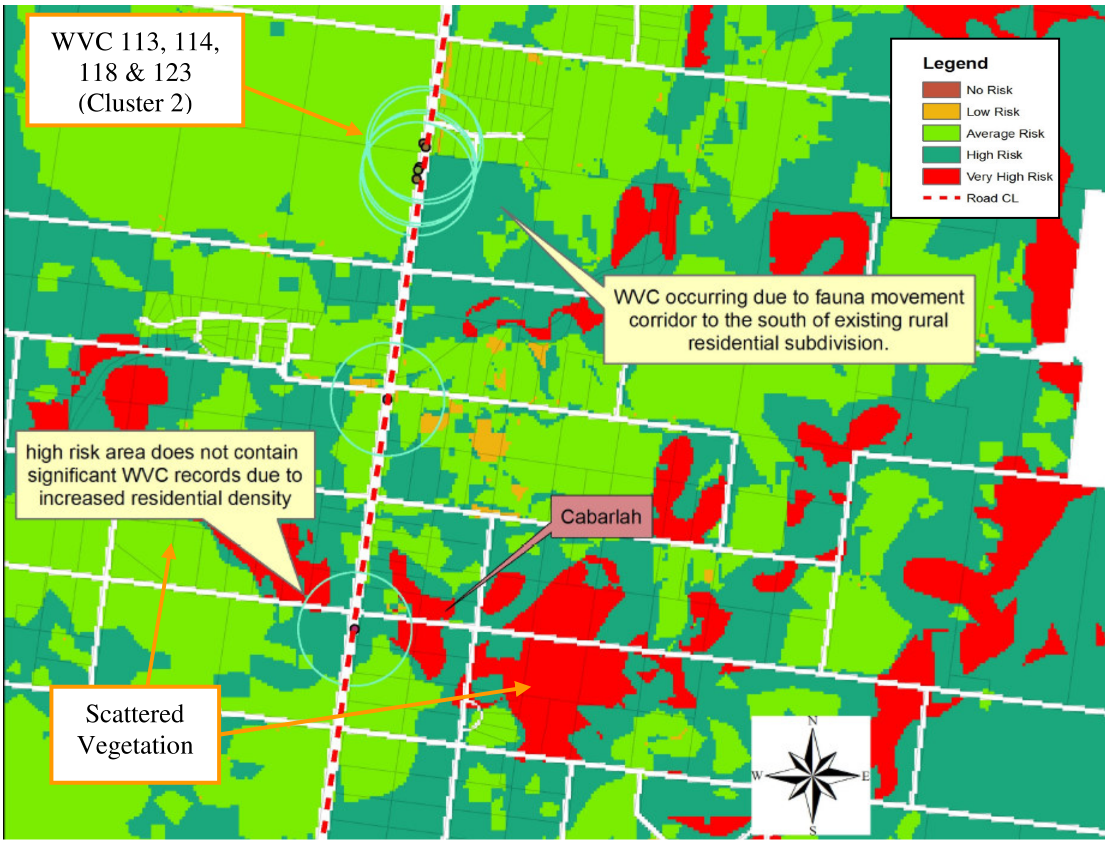

Figure 32. Cluster 2 and predicted risk categories background

Cluster 3 (Fig.23) in this same section of highway occurs in areas with significant roadside remnant vegetation. Road geometry (as previously discussed) may also be playing a part in this cluster of WVCs (Magnus 2006) (appendix Q1).

Cluster 4 consists of mainly arboreal species such as the Common Brushtail Possum. At this position remnant vegetation forms a canopy cover across the NEH. Brushtail possums may therefore use this section of road frequently within their home range area, regularly crossing the road, contributing to high numbers of WVC. It is not known whether these WVCs are actually falling from the canopy or traversing the road.

Appendix P5 (Map 5) is the remainder of the survey route. It contains a large percentage of timber plantations either side of the road and the incidence of WVCs appear to decline and be evenly spread across this section.

It is evident that multiple factors can be affecting the presence of animals in a road corridor and the likelihood of a WVC occurring.

5.7 Future Models

The assessment of multiple species in the same analysis has had limited overall success within this predictive model. It is believed that the diversity of fauna requirements is too vast to incorporate in the same analysis and predictive model. It is recommended that future WVC research should analyse species independently. Ramp et al. (2005) analysed WVCs in species groups. This process may provide greater model accuracy as species-specific landscape needs may be more easily identified.

Classification and regression tree (CART) analysis has been shown to effectively predict the location of animal damage to power line insulators (Kennedy & Baxter 2006). It is believed that CART could be effective in identifying WVCs through analysing variations in landscape variables at multiple spatial scales.

It is also believed that the raster overlay process in conjunction with kernel density estimation and classification & regression tree analysis could significantly improve the prediction of WVC locations.

Chapter 6 Conclusion & Recommendations

This conclusion will focus on the overall project objectives and the project specifications. Recommendations for further research will be abridged at the end of this chapter. Observations, recommendations and conclusions have also been presented throughout the discussion chapter.

6.1 Project objectives & specifications

The projects objectives are outlined in section 1.2. In fulfilling these 3 project objectives a simple, accurate system for the mapping of WVCs has been developed. A Geographic Information System was used to map, analyse and predict WVCs and validation of the predictive model proved that the relationship of WVCs to landscape variables can be a useful tool, but also has limitations.

The project specifications are given in Appendix A. It has been shown from previous research that the reasons for WVCs are complex and interrelated. Four major causes of WVCs have been identified; road design, road user behaviour, animal behaviour and landscape variables. Previous research into developing predictive models for WVCs within Australia has been limited. Through reviewing the literature it became apparent that within Australia the ability to predict WVC locations without presence data is very limited and hence there is a need for this type of research.

Consistency throughout the survey region in landscape characteristics is vital for landscape variable analysis. Increased landscape characteristics will reduce the predictive model integrity. If a predictive model is going to extrapolate WVC locations for a proposed new road, presence data should be obtained from an existing road that has similar design features and landscapes characteristics.

State or federal governments will most likely determine the location of a WVC survey areas through their funding. Reasons for these locations may relate to community concern or government funded civil engineering projects. If regions exhibiting multiple landscape characteristics are to be traversed, the survey route should be segmented to contain only similar characteristics grouped together.

Consistency in landscape characteristics, fauna species requirements and species traits is the key to developing an appropriate prediction of WVC risk areas.

All GIS based projects require current datasets. Building relationships with data custodians is important for gaining access to GIS data that is not commercially available. The relationship developed with the Department of Main Roads enabled this project to gain access to aerial photography and GIS datasets, which were not publicly available. Access to this type information can be vital for the success of a WVC research project. Building and maintaining communication networks with other WVC stakeholders and researchers provides increased access to data and knowledge.

The use of handheld GPS for the location of WVCs has been successful. Handheld GPS was assessed for spatial accuracy in adverse field conditions. The achieved spatial accuracy of the GPS was shown to be greater than that of the GIS datasets to be utilised. The field methods in conjunction with handheld GPS technology can adequately achieve the required spatial accuracy for the location of WVCs. The use of handheld GPS for the location of WVCs is recommended for future WVC research.

This project has designed and developed a system for the location of WVCs. The methodologies in this project have been described in significant detail to assist future WVC research. The location of medium to large sized WVCs through a vehicle based survey technique has been both successful and efficient. It is believed however that smaller fauna species are under-represented using this survey technique.

The use of handheld GPS with digital photography effectively locates and identifies WVCs and adjoining landscape characteristics. The adoption of this technique for all WVCs recorded would provide a significant database for further research.

The methods developed and described in this paper demonstrate a process that can be used to effectively gather, manipulate and input WVC records into a GIS. The use of basic text files was also efficient for the manipulation of coordinate data.

GIS is an effective tool for investigating the relationships of WVCs to the surrounding landscape variables. The system is however limited by accessibility to applicable GIS datasets. The buffer and clip functions used for this project have been effective in extracting percentages of landscape variables. The development of streamlined functions using Model Builder within ArcMap greatly increased the overall efficiency of landscape variable extraction.

The predictive models that were created accomplished the projects objective of associating landscape variables to WVCs. Analysis of the output models verified that WVCs were associated with higher risk areas compared to the averages for the site corridor. However, the success of the predictive models in relation to the occurrence of WVCs within risk category areas has not been determined. The classification of risk category areas requires further research and analysis to determine the probability of WVC occurrence.

The mapping and modelling methods developed in this project have been successful in identifying the relationship between WVCs and landscape variables. However, the complexity of predicting WVCs requires analysis of more than just landscape variables. The methods developed in this paper should be used in conjunction with other modelling techniques and variables that incorporate road geometry, traffic volume, driver behaviour, fauna behaviour and fauna movement corridors. The incorporation of these other variables should substantially increase the ability to predict the locations of WVCs.

6.2 Recommendations

Through the execution of this project a number of important observations have been made. The following points identify limitations of current research and outline recommendations for future research within Australia.

- Future WVCs studies should be undertaken over extended period of time. The increased survey period should allow for seasonal variations. Increased sample sizes would permit statistical analysis and improved model integrity.

- Additional WVC surveys in different landscapes (eg. Hinterland, Downs Plains etc) are needed

- Future research should focus only on species that have similar needs and traits.

- Multiple spatial scale analysis could enhance the prediction of WVC locations. The concept was considered outside the scope of this project, but it is believed that this type of assessment may identify movement corridors.

- Further analysis of landscape connectivity for fauna movements is needed including the influence of patch size, shape and distances to other patches and water on movement paths and WVC incidence.

- Further research into the effectiveness of different datasets is needed to show what types of data provide the best outcomes.

- Reclassification values and raster layer influences need significant further research if the raster overlay process is to be improved for this type of modelling.

- Guidelines that define a classification of 'hotspots' for individual species need to be developed.

- Analysis of the costs associated with the mapping and modelling techniques developed in this paper would be effective in determining its economic efficiency. The determined costs associated with the modelling techniques would allow greater managerial decision-making.

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Appendices

Appendix A - Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG411/2 Research Project
PROJECT SPECIFICATION

FOR:	**George Finlay Johnston**
TOPIC:	Wildlife Vehicle Collision Mapping & Modelling
SUPERVISOR	Dr. Armando Apan
TECHNICAL ADVISOR:	Megan Brady (University of Queensland)
SPONSORSHIP:	Bradston Land Management

PROJECT AIM: The project will use modern GPS surveying techniques to map the location of Wildlife Vehicle Collisions (WVC) at a suitable accuracy for input into a GIS dataset. The project will utilise spatial analysis techniques to examine the relationships between WVC and the surrounding physical and social landscapes. It will also develop a protocol for the recording, analysing and modelling of WVC.

PROGRAMME: **Issue A, 21st March 2007**

1) Research previous studies within Australia and overseas, assessing their techniques and outcomes.

2) Identify the study area for this project.

3) Obtain applicable datasets from relevant data custodians. Build relationships with relevant authorities that may benefit from this research.

4) Assess the spatial accuracy required for GPS data. Acquire appropriate GPS hardware and develop mapping protocols that will meet both data acquisition and positional accuracy benchmarks.

5) Develop methodologies and undertake the field survey to capture WVCs.

6) Reduce, audit, collate and input all data acquired from field survey.

7) Use GIS software to view, manipulate and assess datasets. Investigate possible relationships between WVC data and surrounding natural and human features in landscapes.

8) Devise modelling techniques that will correlate relationships of WVCs to surrounding landscapes. Validate or assess the accuracy of the model.

AGREED: ________ (Student) ________ (Supervisor)

(dated) 23 / 03 / 07 (dated) 28 / 03 / 07

CO-EXAMINER:

Appendix B - Garmin Handheld GPS raw file

Example.txt

Grid	UTM
Datum	WGS 84

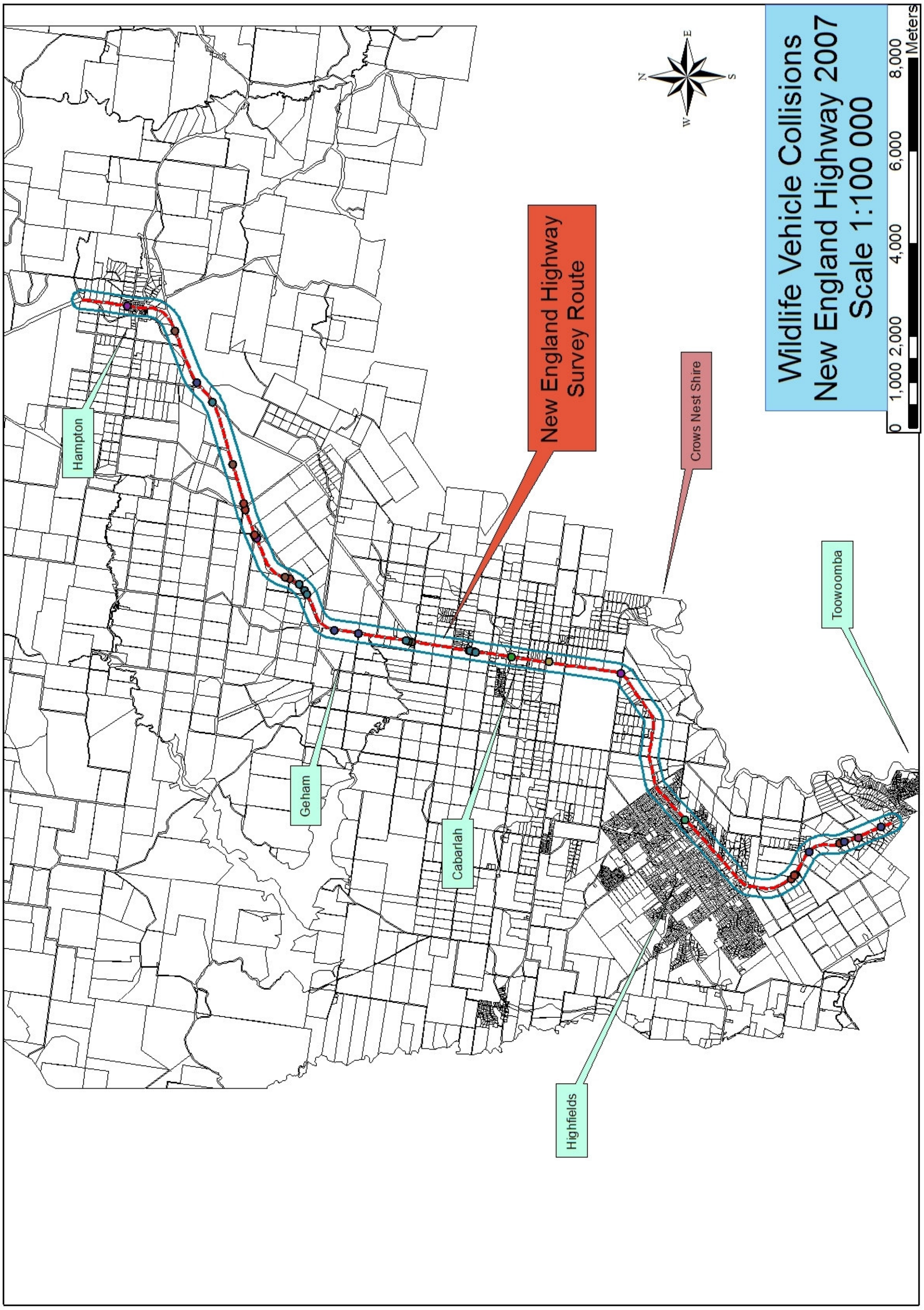
Header	Name	Description	Type	Position	Altitude	Depth	Proximity	Temperature
Waypoint	001	01-AUG-07 12:39:44	User Waypoint		56 J 399990 6963315			636 m
Waypoint	002	01-AUG-07 12:46:22	User Waypoint		56 J 400478 6966587			598 m
Waypoint	003	01-AUG-07 12:55:19	User Waypoint		56 J 401783 6970174			606 m
Waypoint	004	01-AUG-07 12:55:20	User Waypoint		56 J 401779 6970169			604 m
Waypoint	005	01-AUG-07 13:02:02	User Waypoint		56 J 403524 6971446			679 m
Waypoint	006	01-AUG-07 13:08:35	User Waypoint		56 J 401777 6970174			603 m
Waypoint	007	01-AUG-07 13:13:30	User Waypoint		56 J 403669 6971484			675 m

Header	Name	Start Time	Elapsed Time	Length	Average Speed		Link
Track	ACTIVE LOG		1/08/2007 12:12:07 PM		00:09:06	5.86 km	39 kph

Header	Position	Time	Altitude	Depth	Leg Length	Leg Time	Leg Speed	Leg Course			
Trackpoint		56 J 397019 6954266			1/08/2007 12:12:07 PM		575 m				
Trackpoint		56 J 396962 6954278			1/08/2007 12:12:45 PM		582 m	57.9 m	00:00:38	5.5 kph	283° true
Trackpoint		56 J 396951 6954278			1/08/2007 12:12:58 PM		582 m	10.6 m	00:00:13	2.9 kph	274° true
Trackpoint		56 J 396953 6954279			1/08/2007 12:13:20 PM		600 m	1.47 m	00:00:22	0.24 kph	62° true
Trackpoint		56 J 396952 6954280			1/08/2007 12:14:01 PM		613 m	1.14 m	00:00:41	0.10 kph	354° true
Trackpoint		56 J 396985 6954406			1/08/2007 12:14:38 PM		616 m	131 m	00:00:37	13 kph	15° true
Trackpoint		56 J 397063 6954547			1/08/2007 12:15:14 PM		616 m	162 m	00:00:36	16 kph	29° true
Trackpoint		56 J 397094 6954603			1/08/2007 12:15:21 PM		617 m	63.7 m	00:00:07	33 kph	29° true
Trackpoint		56 J 397149 6954705			1/08/2007 12:15:30 PM		619 m	116 m	00:00:09	46 kph	29° true

Appendix C – Landscape variable WVC extraction (Land Use)

Appendix D - Survey Route



Appendix E - LISCAD Alignment Report

LISCAD Report: Point Report By Alignment
Sunday, 14 October 2007 10:28

Projection type: Australian Map Grid Zone 56

Alignment: Channel Right

Distance Units: Metres
Offsets denoted with a '*' are horizontal distances from the reported chainage to the point.
True (perpendicular) offset was not calculated.

Point ID	Distance	Offset	Description
1	2660.047	-17.365	NBBANDICOOT
2	18349.578	-5.663	UNKNOWN
3	18348.650	-6.035	BTLPOSSUM
4	19989.601	-2.609	WALLABY
7	18327.478	-12.363	BTLPOSSUM
8	18375.955	-6.947	BTLPOSSUM
10	1225.647	7.260	NBBANDICOOT
11	1115.088	14.398	HARE
12	261.827	8.360	HARE
13	15037.311	-20.850	HARE
14	13865.219	-12.802	WALLABY
15	18332.671	1.572	BTLPOSSUM
16	18309.451	3.044	BTLPOSSUM
17	18303.136	2.668	BTLPOSSUM
19	11683.612	-3.727	MACROPOD
20	2521.481	-3.252*	NBBANDICOOT
21	2546.402	-12.606	NBBANDICOOT
22	18385.797	-1.926	NBBANDICOOT
23	1951.686	-11.733	HARE
24	17097.250	0.853	NBBANDICOOT
101	9284.543	4.901	BTLPOSSUM
102	12594.521	-16.511	KANGAROO
104	16686.045	-4.879	KANGAROO
105	18960.236	-7.684	NBBANDICOOT
106	16687.740	-9.992	KANGAROO
107	19110.214	-4.290	NBBANDICOOT
108	21414.572	-2.255	KANGAROO
109	23165.145	4.997	WALLABY
110	16860.473	11.126	KANGAROO
111	13939.216	-12.186	MACROPOD
112	5616.908	-9.847	RTLPOSSUM
113	12510.486	-16.702	KANGAROO
114	12499.838	-20.120	WALLABY
115	17198.064	0.336	WALLABY
116	24453.846	-0.167	BTLPOSSUM
117	15560.293	-24.670	HARE
118	12583.195	-4.641	KANGAROO
119	16591.779	-7.598	KANGAROO
120	21953.176	-9.588	HARE
121	13997.619	-14.201	KANGAROO
122	808.066	-15.802	UNKNOWN
123	12466.452	-20.029	KANGAROO
9	10865.296	4.045	KANGAROO

Listed 43 of 173 points.

Appendix F - Surveyed WVC database file

WAYPT	DATE	SPECIES	EASTING	NORTHING	ZONE	ELEVATION	PHOTO No.
1	1-Feb-07	NBBANDICOOT	395538	6959628	56	674	1-3
2	1-Feb-07	UNKNOWN	402952	6971232	56	657	4-6
3	1-Feb-07	BTLPOSSUM	402951	6971232	56	658	7-9
4	1-Feb-07	WALLABY	404513	6971730	56	678	10-12
7	7-Feb-07	BTLPOSSUM	402929	6971230	56	686	13-15
8	7-Feb-07	BTLPOSSUM	402976	6971243	56	680	16-18
9	7-Feb-07	KANGAROO	400237	6964875	56	642	19-21
10	7-Feb-07	NBBANDICOOT	396310	6958570	56	682	22-24
11	7-Feb-07	HARE	396354	6958470	56	680	25-27
12	7-Feb-07	HARE	396672	6957679	56	689	28-30
13	9-Feb-07	HARE	400848	6969001	56	562	31-33
14	9-Feb-07	WALLABY	400675	6967842	56	563	34-36
15	21-Feb-07	BTLPOSSUM	402939	6971219	56	674	37-39
16	21-Feb-07	BTLPOSSUM	402918	6971209	56	669	40-42
17	21-Feb-07	BTLPOSSUM	402912	6971207	56	666	43-45
18	11-Feb-07	SNAKE	400986	6969731	56	586	46-48
19	11-Feb-07	MACROPOD	400352	6965685	56	618	49-51
20	15-Feb-07	NBBANDICOOT	395646	6959538	56	664	52-54
21	16-Feb-07	NBBANDICOOT	395621	6959548	56	651	55-57
22	21-Feb-07	NBBANDICOOT	402987	6971242	56	648	58-60
23	22-Feb-07	HARE	396127	6959238	56	669	61-63
24	22-Feb-07	NBBANDICOOT	402030	6970488	56	636	64-66
101	1-Aug-07	BTLPOSSUM	399990	6963315	56	636	67-69
102	1-Aug-07	KANGAROO	400478	6966587	56	598	70-72
104	1-Aug-07	KANGAROO	401779	6970169	56	604	73-75
105	1-Aug-07	NBBANDICOOT	403524	6971446	56	679	76-78
106	1-Aug-07	KANGAROO	401777	6970174	56	603	79-81
107	1-Aug-07	NBBANDICOOT	403669	6971484	56	675	82-84
108	1-Aug-07	KANGAROO	405868	6972162	56	693	85-87
109	1-Aug-07	WALLABY	407396	6972973	56	719	88-90
110	1-Aug-07	KANGAROO	401915	6970279	56	641	91-93
111	1-Aug-07	MACROPOD	400687	6967915	56	550	94-97
112	6-Aug-07	RTLPOSSUM	396819	6961915	56	658	98-100
113	6-Aug-07	KANGAROO	400465	6966504	56	593	101-103
114	6-Aug-07	WALLABY	400460	6966494	56	592	104-107

115	6-Aug-07	WALLABY	402064	6970583	56	633	108-111
116	6-Aug-07	BTLPOSSUM	407953	6974008	56	720	112-114
117	6-Aug-07	HARE	400926	6969518	56	565	115-118
118	6-Aug-07	KANGAROO	400488	6966574	56	583	119-121
119	8-Aug-07	KANGAROO	401701	6970119	56	600	112-114
120	8-Aug-07	HARE	406279	6972507	56	705	115-117
121	11-Aug-07	KANGAROO	400694	6967973	56	544	118-120
122	16-Aug-07	UNKNOWN	396440	6958174	56	679	121-123
123	16-Aug-07	KANGAROO	400455	6966461	56	595	124-126

Appendix G - Landscape variable percentages

Description	% District Zone {Site Corridor}	% District Zone {WVC}	% Difference
Special Purpose	18.2	19.5	1.3
Residential B	7.5	1.5	-6.0
Rural A	47.9	56.6	8.7
Village	1.1	1.0	-0.1
Special Facilities	2.5	1.1	-1.4
Open Space	0.8	0.7	-0.1
Central Business	0.2	0.1	-0.1
Rural B	7.3	7.5	0.2
Rural Residential B	9.8	7.7	-2.1
Rural Residential A	4.6	4.3	-0.3
Description	**% FPC {Site Corridor}**	**% FPC {WVC}**	**% Difference**
closed forest	0.5	0.3	-0.2
dense woodland	0.6	0.7	0.1
non-wooded	53.0	46.2	-6.8
open forest I	10.5	12.1	1.6
open forest II	13.3	17.9	4.5
open woodland	0.2	0.7	0.4
thick open forest	12.3	7.5	-4.7
thick woodland	0.5	0.4	-0.1
thin open forest	7.0	11.0	4.0
thin open woodland	0.0	0.0	0.0
thin woodland	1.3	2.8	1.6
woodland	0.7	0.4	-0.4
Description	**% DCDB Area {Site Corridor}**	**% DCDB Area {WVC}**	**% Difference**
0-500m²	1.3	3.7	2.4
501-1000m²	3.6	2.5	-1.1
1001-4000m²	42.8	16.9	-25.8
4001-6000m²	5.9	8.8	2.9
6001m²-10ha	27.8	32.2	4.4
10ha - 40ha	13.3	29.1	15.8
40ha-100ha	4.2	4.5	0.3
>100ha	1.0	2.3	1.2
Description	**% Land Use {Site Corridor}**	**% Land Use Area {WVC}**	**% Difference**
bare - unspecified	0.1	0.1	0.0
crop - broadacre	8.8	6.6	-2.2
native vegetation	34.0	45.6	11.6

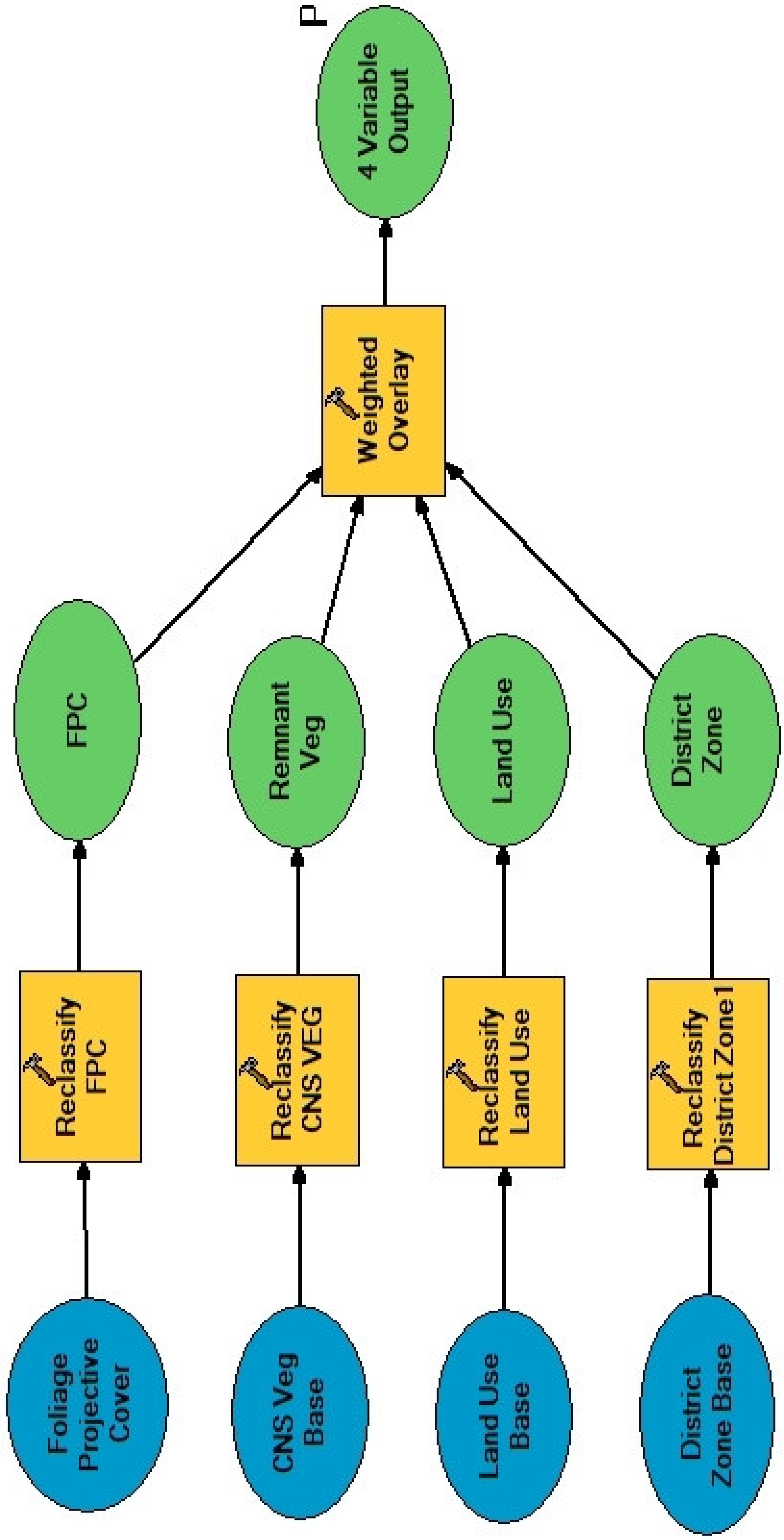
orchard	2.5	0.1	-2.4
pasture	28.8	28.5	-0.4
plantation	8.9	6.2	-2.7
regrowth	2.4	5.2	2.8
settlement	14.6	7.9	-6.7
Unclassified	0.0	0.0	0.0
Water	0.0	0.0	0.0
Description	**% Remnant Veg {Site Corridor}**	**% Remnant Veg {WVC}**	**% Difference**
Clear	77.59	79.81	2.22
Fringing	0.07	0.30	0.23
Plantation	8.63	5.79	-2.84
Tall forest	12.25	14.10	1.85
Grassy woodland	0.00	0.00	0.00
Open forest	1.46	0.00	-1.46
Rainforest	0.00	0.00	0.00
vine thicket	0.00	0.00	0.00
Shrubby forest	0.00	0.00	0.00
Woodland	0.00	0.00	0.00
n/a	0.00	0.00	0.00

Appendix H - Variable Weights and Reclassification Values

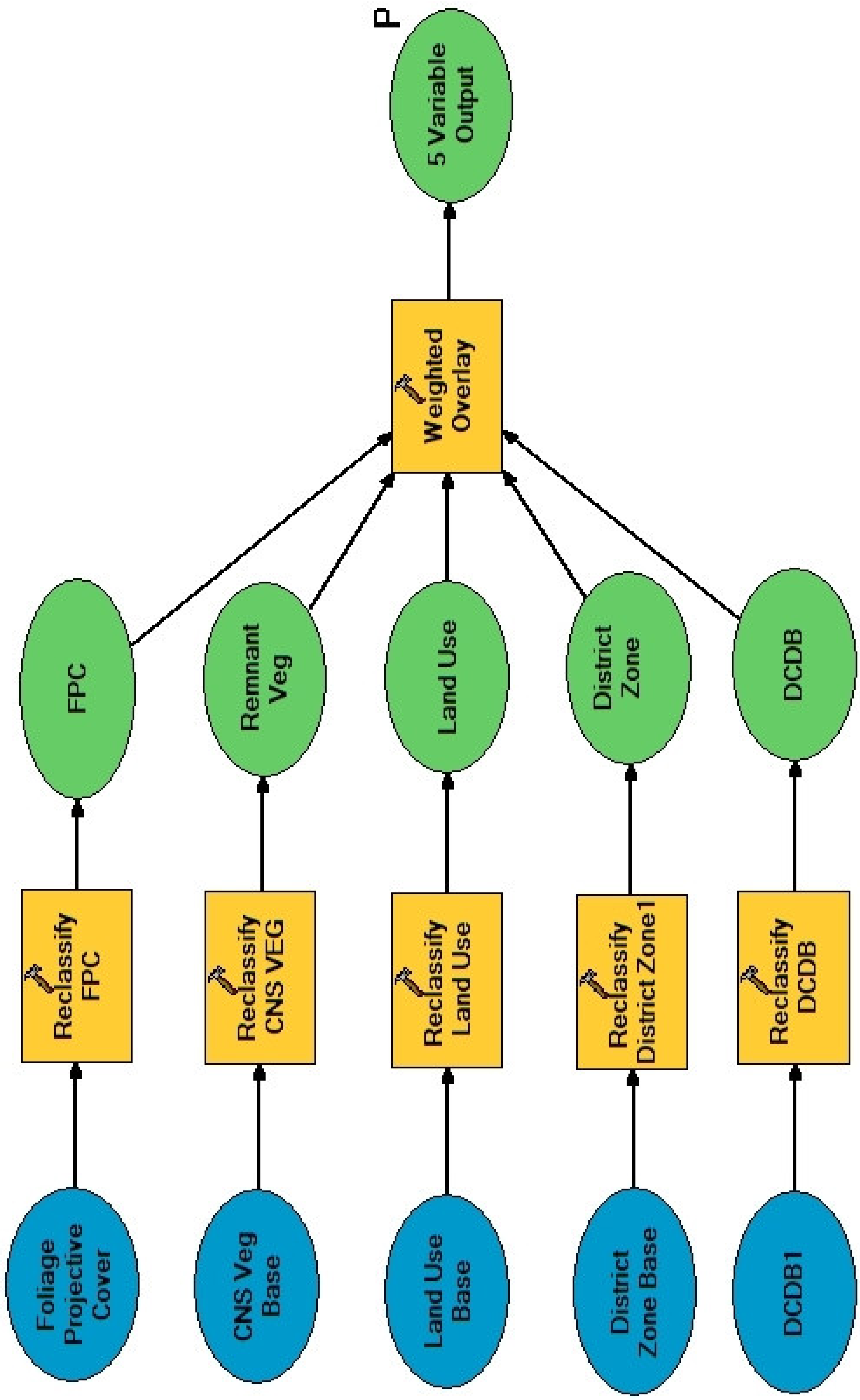
Dataset	W (4V)	W (5V)	W(6V)	Description	Reclass
FPC	25%	20%	20%	closed forest	1
				dense woodland	2
				non-wooded	1
				open forest I	4
				open forest II	5
				open woodland	3
				thick open forest	1
				thick woodland	1
				thin open forest	5
				thin open woodland	4
				thin woodland	1
				woodland	1
				No Data	1
District Zones	25%	20%	20%	Special Purpose	3
				Residential B	1
				Rural A	5
				Village	1
				Special Facilities	1
				Open Space	1
				Central Business	1
				Rural B	2
				Rural Residential B	1
				Rural Residential A	1
				No Data	1
Land Use	25%	20%	20%	bare - unspecified	2
				crop - broadacre	1
				native vegetation	5
				orchard	1
				pasture	1
				plantation	1
				regrowth	1
				settlement	1
				Unclassified	1
				Water	1
				No Data	1
Remnant Veg	25%	20%	20%	Clear	5
				Fringing	2
				Plantation	1
				Tall forest	5
				Grassy woodland	1
				Open Forest	1
				Rainforest	1
				Semi-evergreen vine thicket	1
				Shrubby forest	1
				Woodland	1
				n/a	1
				No Data	1

Dataset	W (4V)	W (5V)	W(6V)	Description	Reclass
DCDB	**---**	20%	10%	0-500m²	2
				501-1000m²	1
				1001-4000m²	1
				4001-6000m²	2
				6001m²-10ha	3
				10ha - 40ha	5
				40ha-100ha	2
				>100ha	2
				No Data	3
DEM (Aspect)	**---**	**---**	10%	Flat	1
				N	4
				NE	4
				E	3
				SE	3
				S	2
				SW	3
				W	5
				NW	5
				N	4
				No Data	1

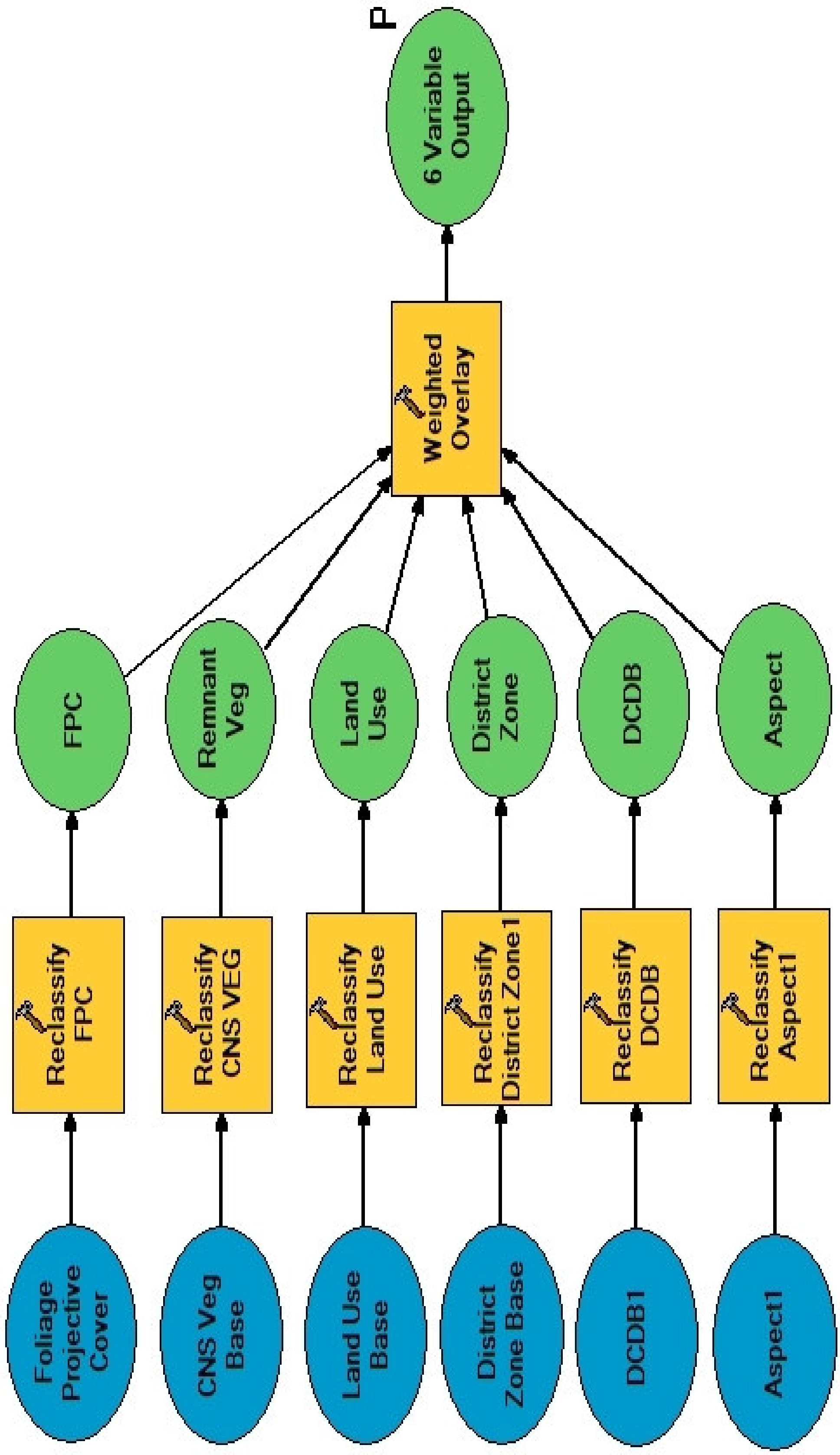
Appendix I - Model Builder schematic (4 variables)



Appendix J - Model Builder schematic (5 variables)



Appendix K - Model Builder schematic (6 variables)



Appendix L – PSM No.104955 (Form 6)

Queensland Government
Natural Resources and Water

Survey Search Detail Report
Details of Registered Number: 104955

Page: 1 of 1

Current Information			
Administrative			
Alternate Name(s)	CROWS NEST		
Parish	CROWS NEST		
Town	CROWS NEST		
Local Authority	CROWS NEST		
Locality Description	SW CHARLES/PARKLAND		
Related Information			
Mark Details			
Mark Type	STAND	**Mark Condition**	GOOD
Installed By	A WOLRIGE	**Installed Date**	14/05/1993
Last Visited	10/02/2006	**Sketch Available**	YES
Connection(s)	SP189213		
	SP169797		
	SP162212		
	RP888589		
	RP850836		
Horizontal			
Datum	GDA94		
Latitude	27°16' 5.8256" S	**Longitude**	152°3' 32.5506" E
Easting	406862.783	**Northing**	6983498.756
Zone	56		
Order	1st ORDER	**Class**	CLASS A
Adjustment Name	GDA - QLD SUPPLEMENTARY AREA 2 AND 3	**Fixed By**	GPS
Prominent Feature	NO		
Vertical			
Height	543.367	**Datum**	AHD D
Order	4th ORDER	**Class**	Class D
Fixed By	GPS	**Origin**	GPS
Geoid/Ellipsoid Separation(N)	14.321		
Model	AUSGEOID98		

The Survey Co-ordination Act of 1952-1981
(Regulation 16)
FORM 6

QUEENSLAND

REGD. No. 104955

PERMANENT MARK SKETCH PLAN

Other Ref. No.

Description of Mark STANDARD PLAQUE D.M.S. District TOOWOOMBA

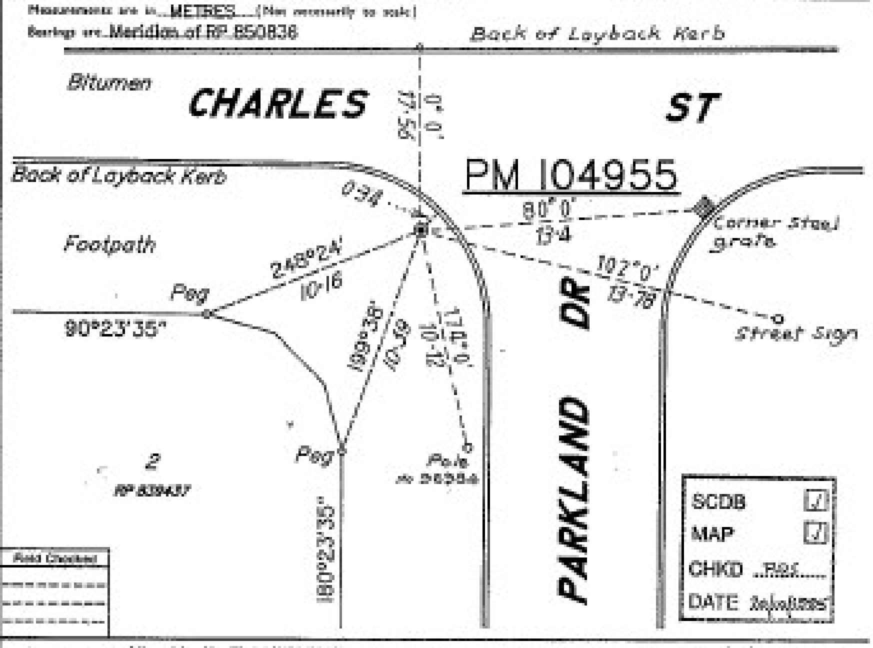
Parish of CROWS NEST City or Town of CROWS NEST

Local Authority CROWS NEST SHIRE COUNCIL Map 9343-344

PLEASE LEAVE THIS MARGIN VACANT

PERMANENT SURVEY MARK INSTALLATION DETAILS

Measurements are in METRES (Not necessarily to scale)
Bearings are Meridian of RP 850836



Field Checked

Installed by Allan Martin Field WOLRIGE Date 14/5/1993
Placed in Connection with (Type of survey/project) CADASTRAL survey Plan and / or Field Bk. Ref. RP 850836
Connd. on Cadastral Plan No. RP 850836

VERTICAL DATA

AUSTRALIAN HEIGHT DATUM (This section to be completed by D.M.S. when Official Lin-adj. Values are available)
Adj. Height .... Analysis Ref. .... L. Book No. ....
Origin Secn. .... Secn. Nos .... Book No. ....

OTHER DATUMS (Relevant information columns to be completed in full)
Reduced Level (i) .... A.H.D. (etc.) (ii) .... Datum Adopted (i) A.H.D. (ii) .... L. Book No. (i) .... (ii) ....
Levelled by (i) .... (ii) .... Date (i) .... (ii) ....
Origin Mark (i) .... (ii) .... Origin R.L. (i) .... (ii) ....

HOR DATA

A.M.G. CO-ORDINATES E .... N .... Zone .... Date ....
Origin Stns. for Co-ordinates with values adopted (i) .... E .... N .... (ii) .... (iii) ....
Local Co-ords. available on Plan Ref. .... Estab. by ....

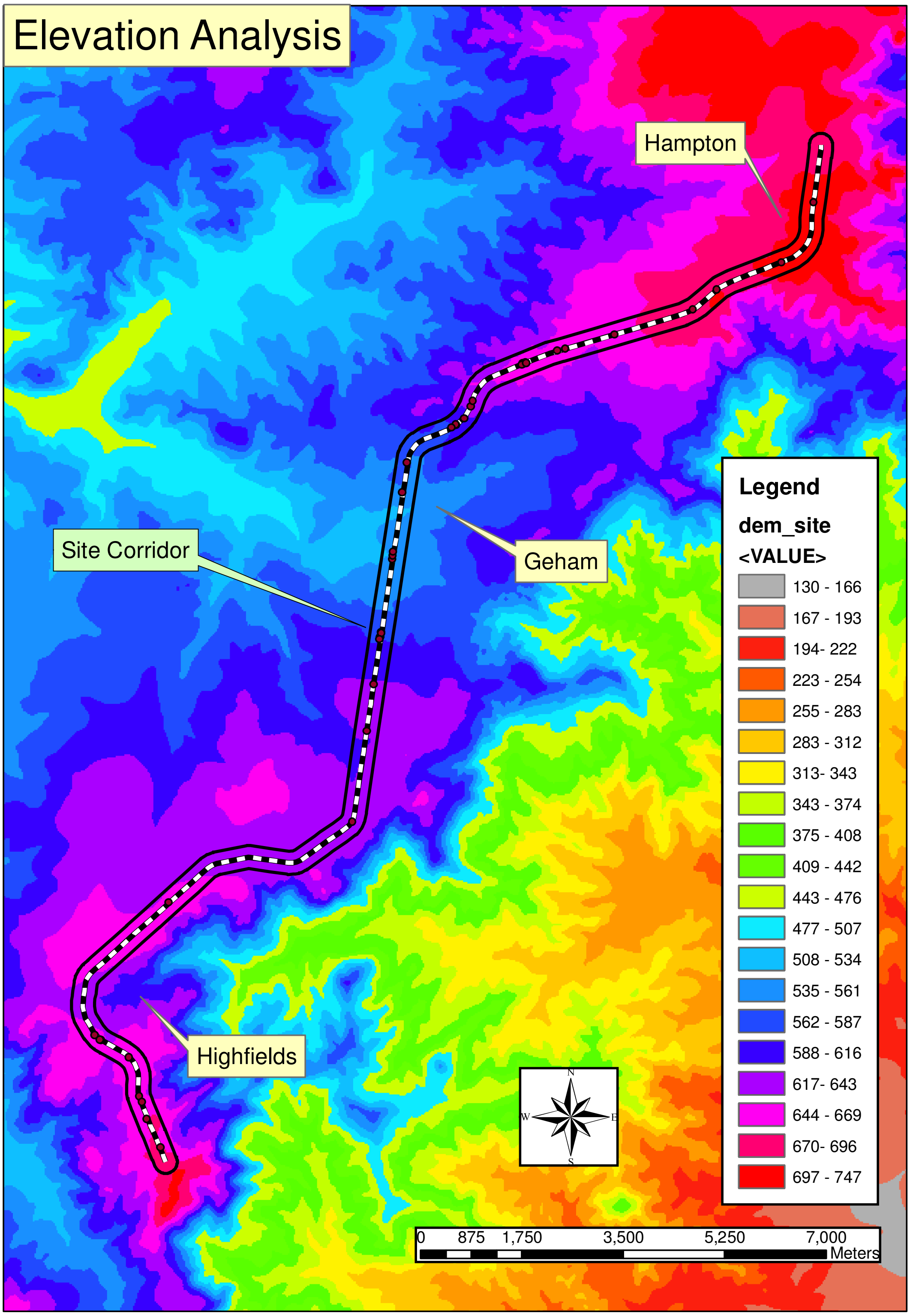
Amended

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952-1981".

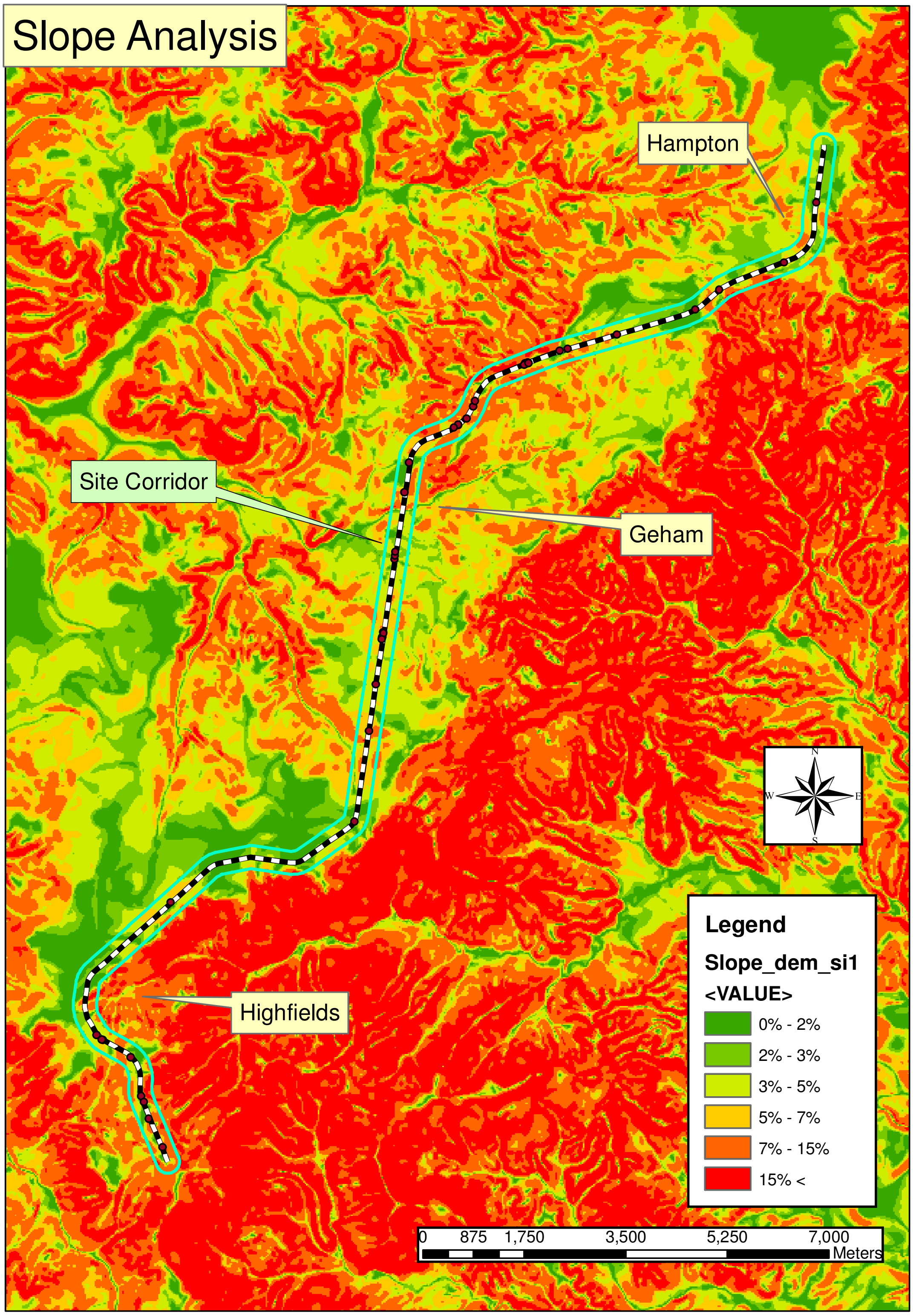
Date 12th July 1995 Signature [illegible]
Authority Licensed Surveyor

104955
SCS104955

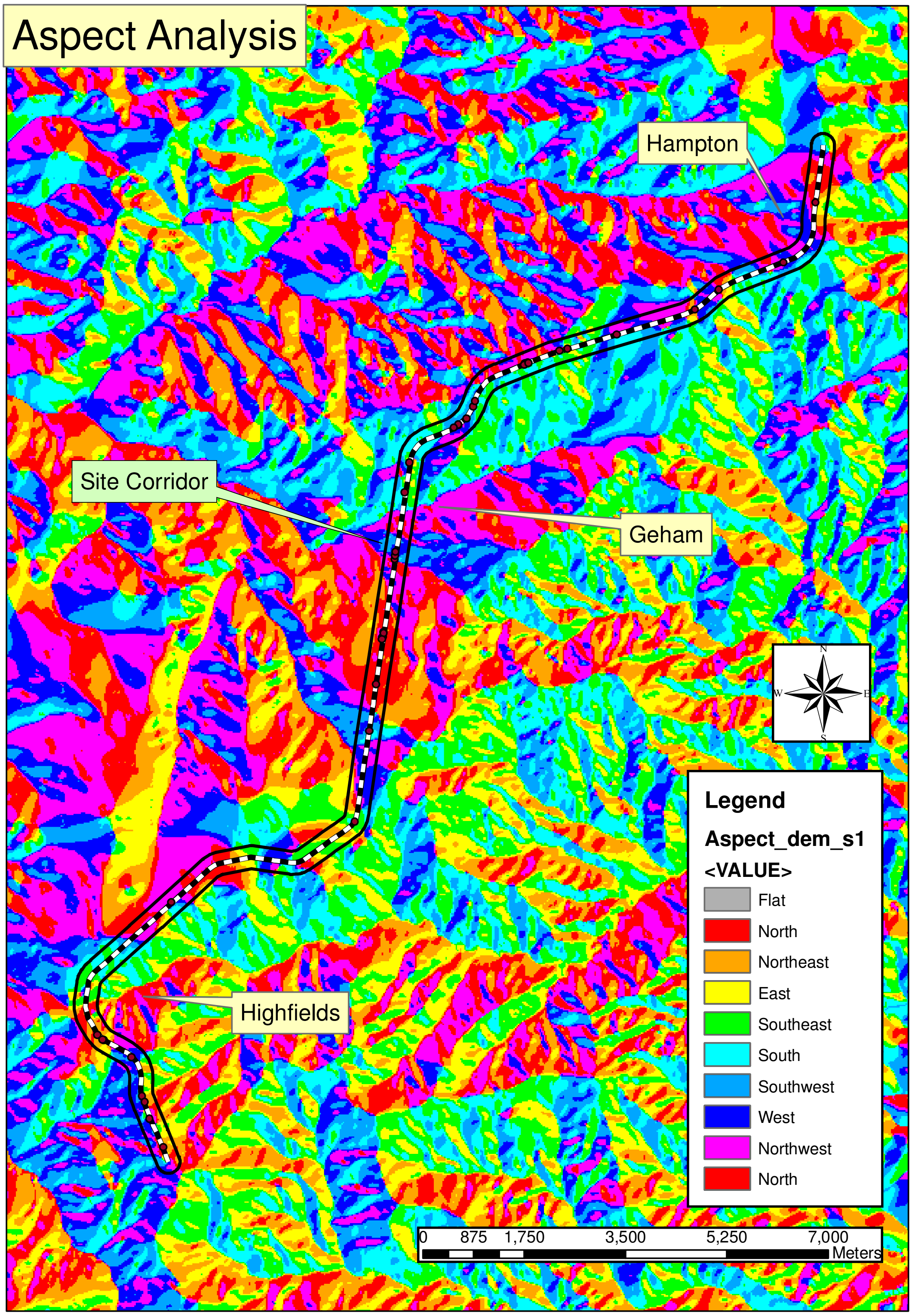
Appendix M – Digital Elevation Model



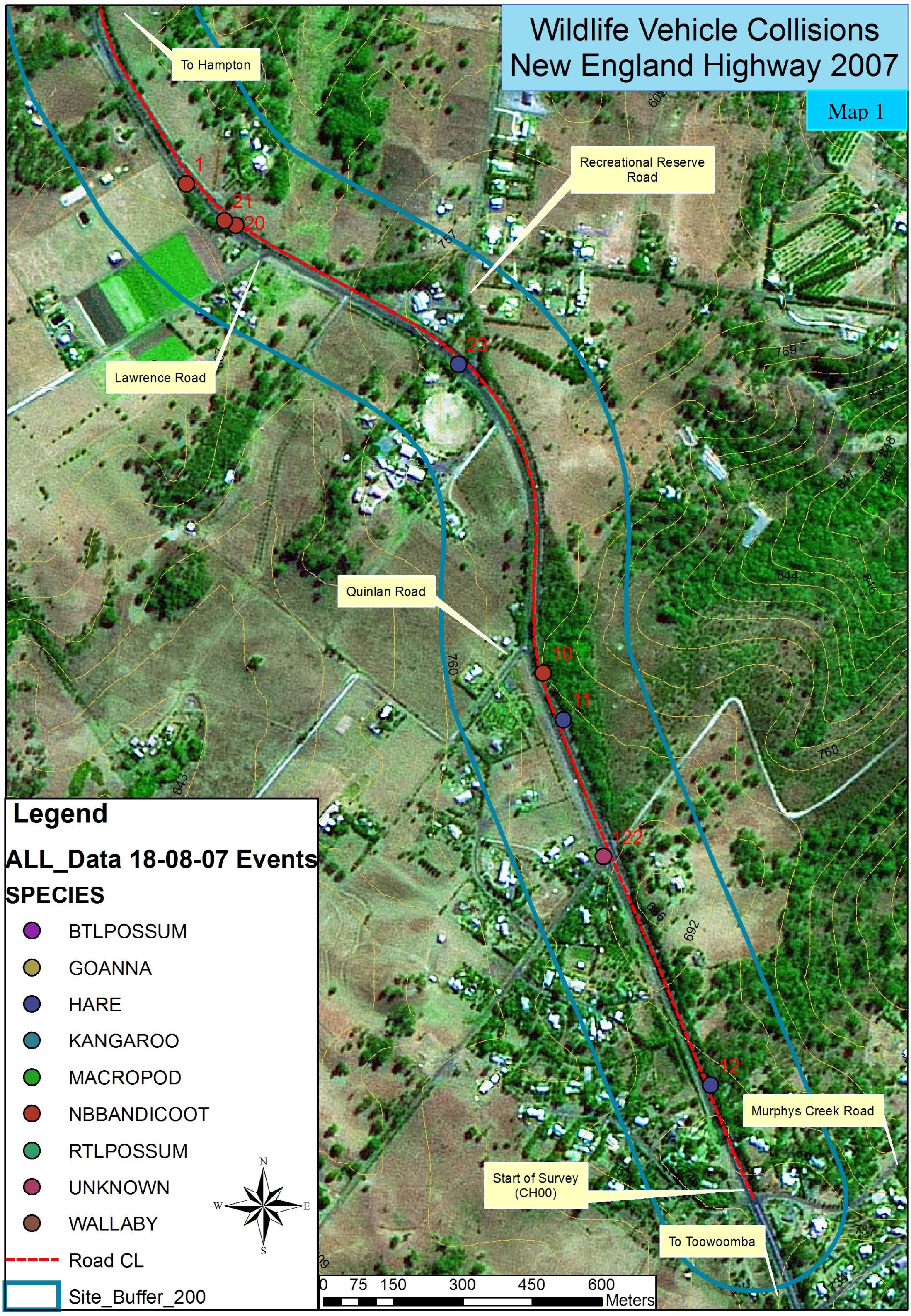
Appendix N – DEM Slope



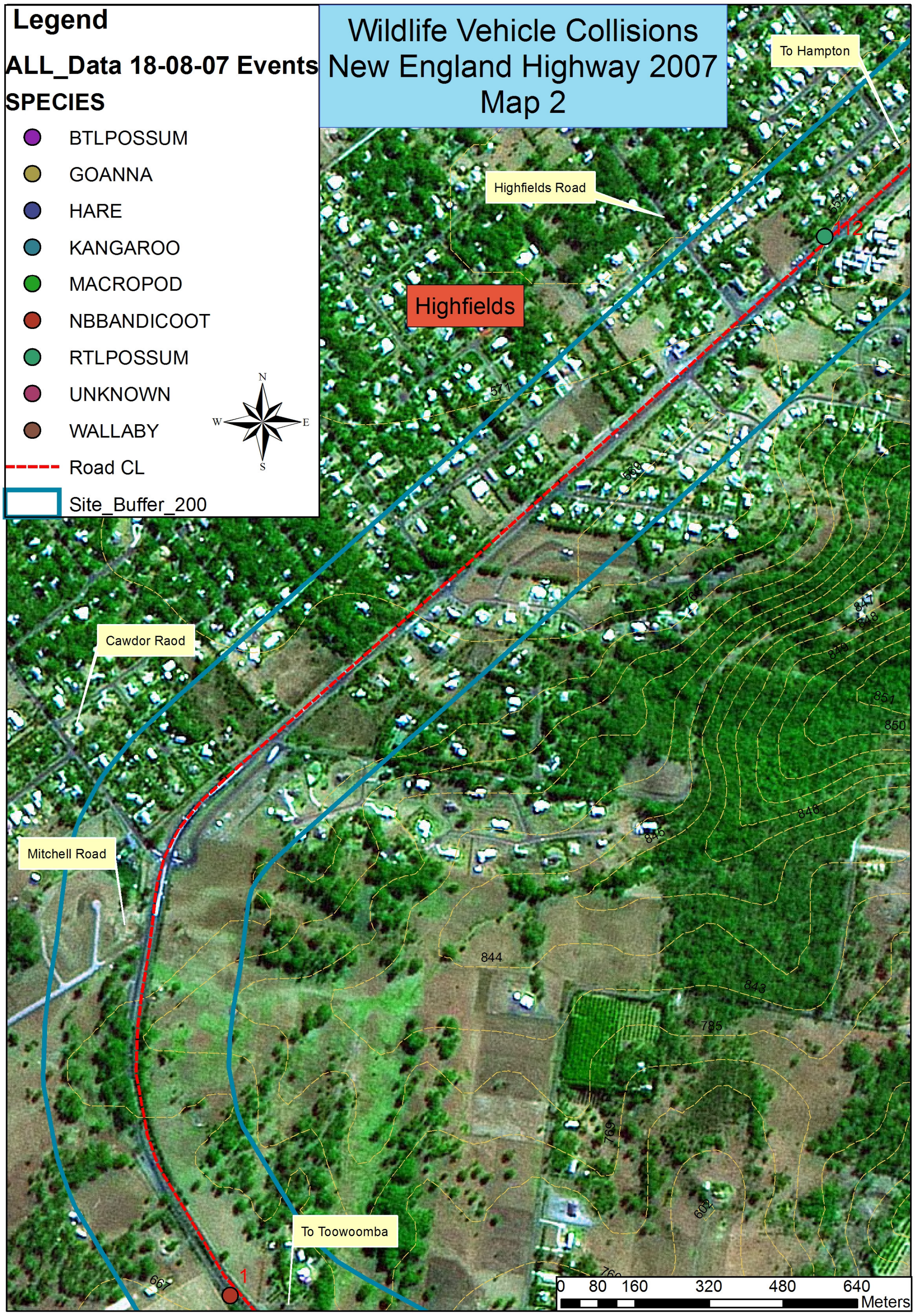
Appendix O – DEM Aspect



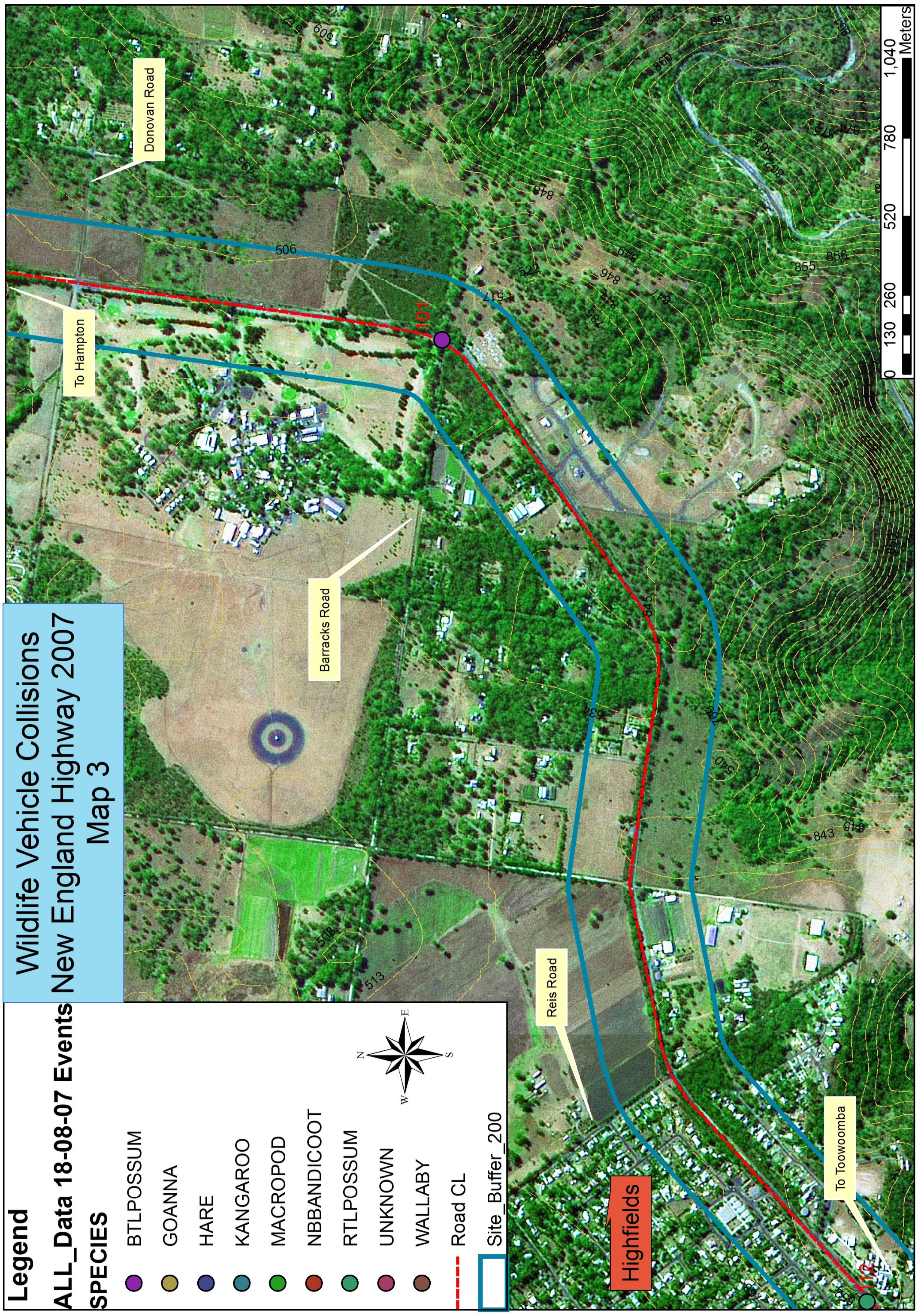
Appendix P1 – Satellite Imagery Map 1



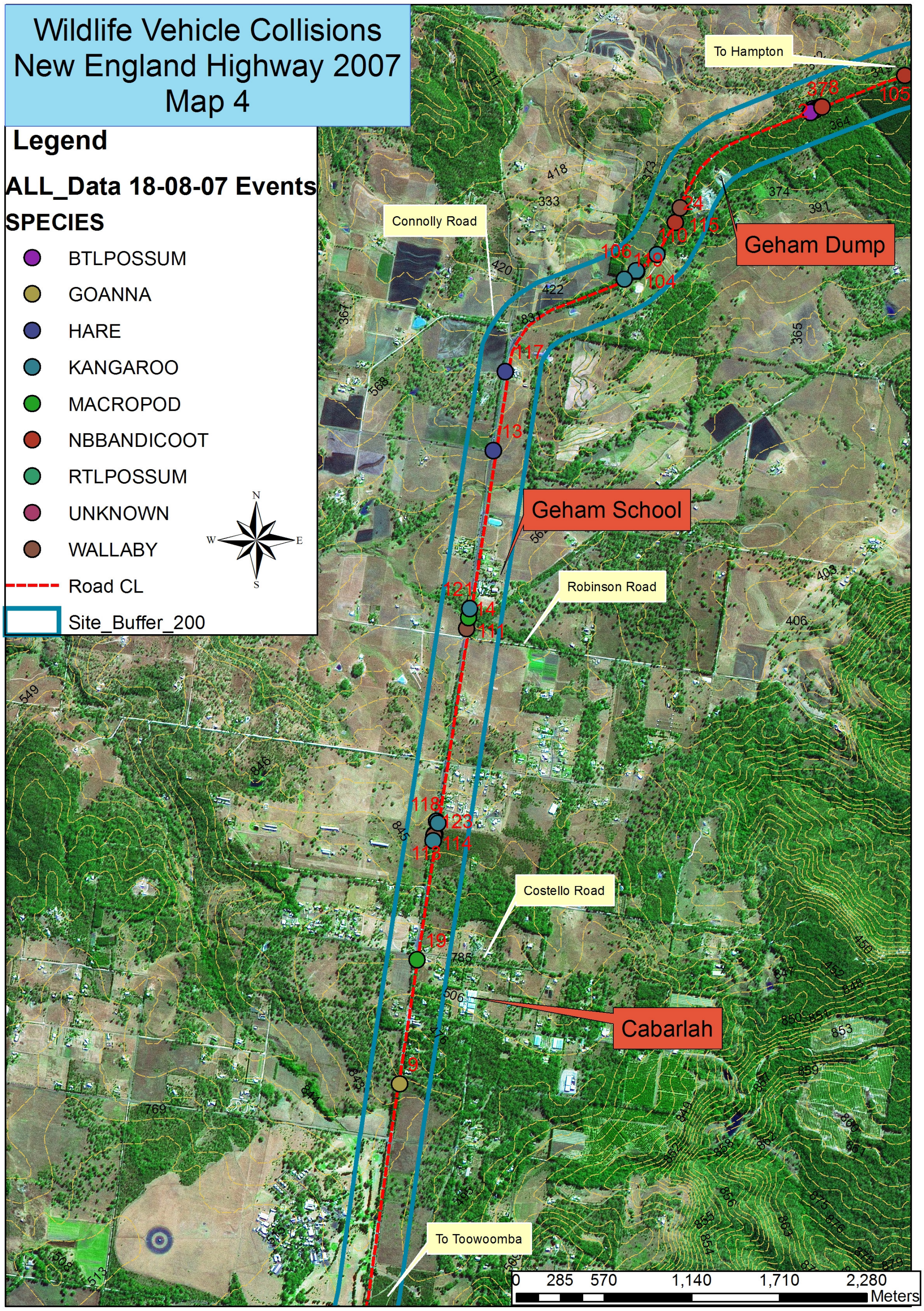
Appendix P2 – Satellite Imagery Map 2



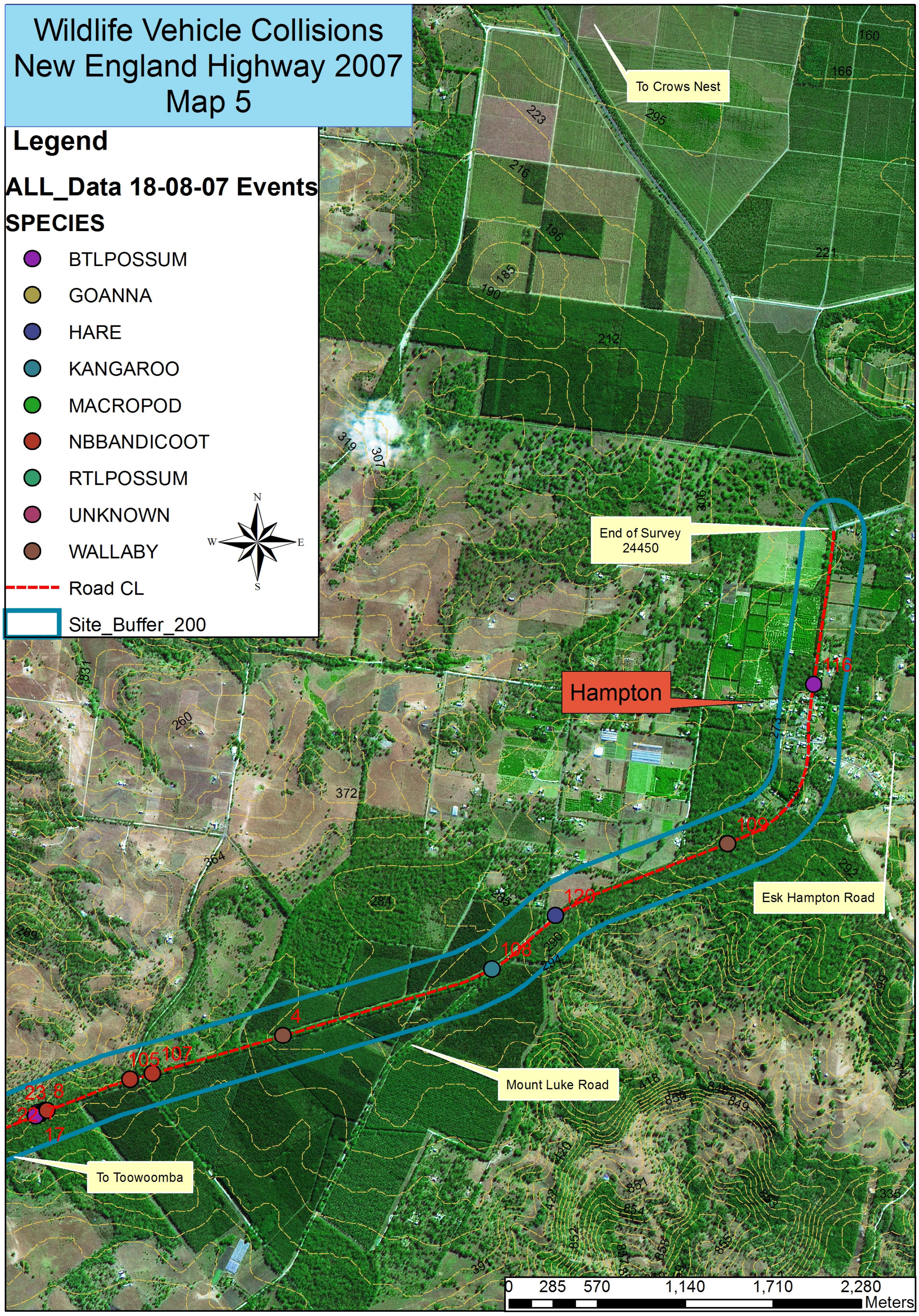
Appendix P3 – Satellite Imagery Map 3



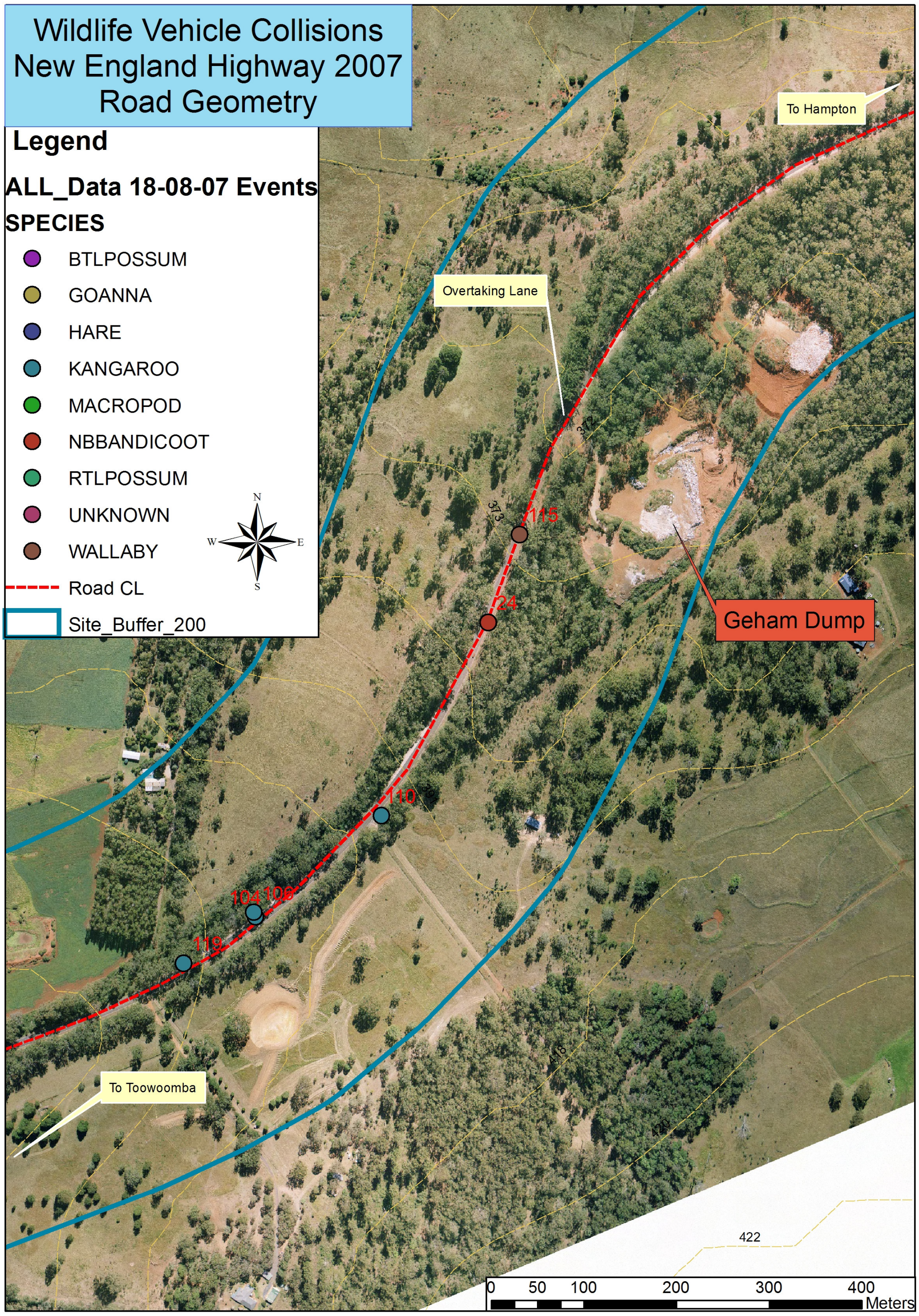
Appendix P4 – Satellite Imagery Map 4



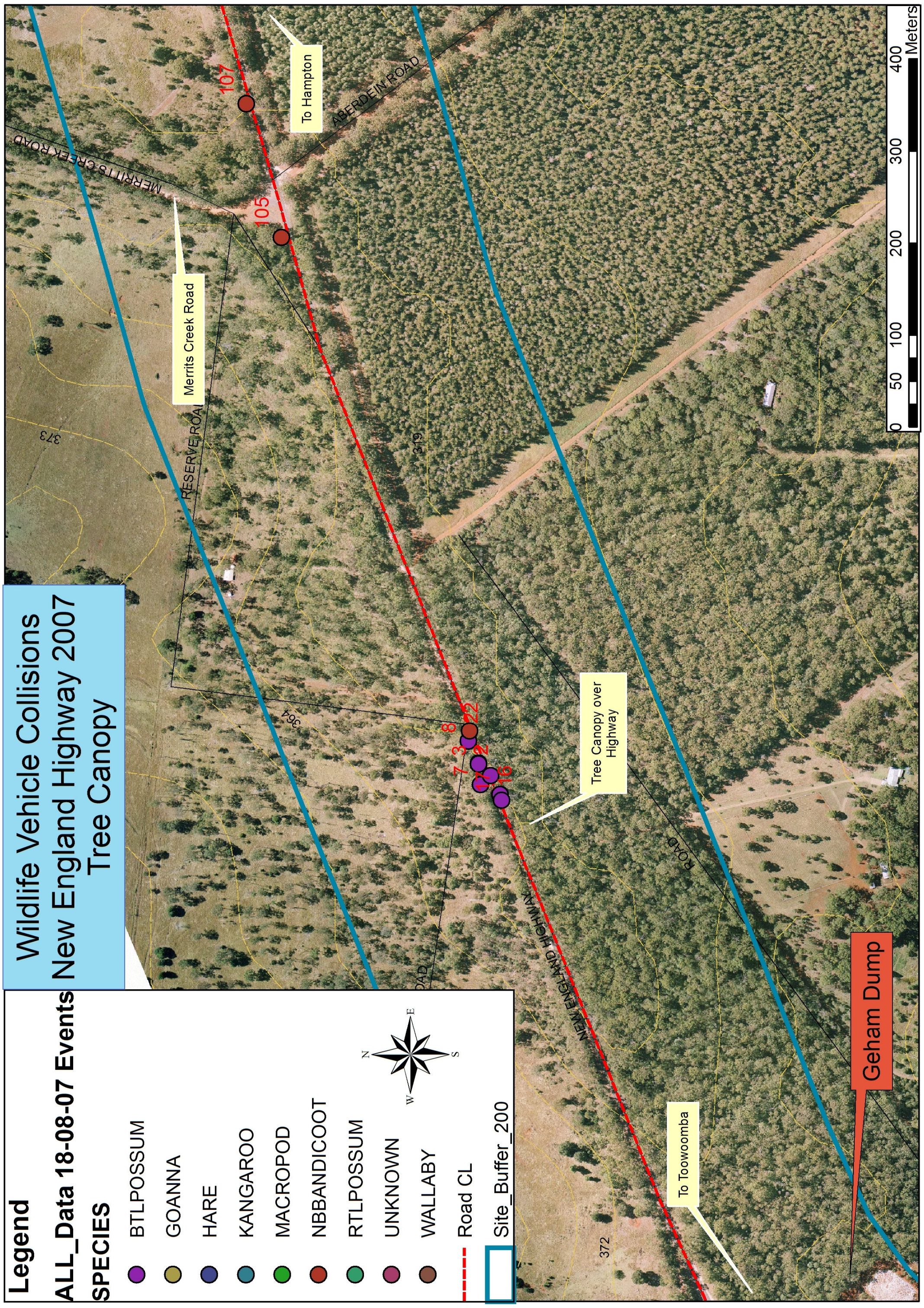
Appendix P5 – Satellite Imagery Map 5



Appendix Q1 – Road Geometry



Appendix Q2 – Tree Canopy Cover



Appendix R – WVC (018) Photographs